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ELEMENTS OF
NATURAL PHILOSOPHY

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ELEMENTS
OF
NATURAL PHILOSOPHY

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PREFACE

THIS book has been written for the use of beginners, and more particularly for those who are in a position to carry on practical work in Science. The day has happily passed away, when a passive attendance at a course of lectures, relieved though they might be by astonishing experiments, was regarded as an adequate training in Science. The right aims of scientific education are now fortunately recognised to be a habit of inquiry, an attitude of personal independence and of personal responsibility in the face of problems, and a keen desire to undertake research into the facts of nature, even when second-hand information is accessible. The course of work suggested in these pages is offered, in that spirit, to the large class of workers who value education more than information. It is intended as a handbook for the laboratory, to contain a short account of the main ideas that everyone must make his own, before he can undertake higher work with any measure of success. And these ideas are most permanently grasped through the medium of practical discovery. Subjects for investigation are frequently suggested, and it is everywhere insisted, that practice in observation is even more important than the verification of established truths. The highest duty of teachers is to train up workers, rather than to impart, regardless of capacity, the maximum of knowledge.

In 1890, Messrs. Longmans published *Laboratory Work*, a book in which I endeavoured to show, that an elementary course of Science need not be bound down to the conventional limits of Physics or Chemistry. It has been usual for a boy to define his educational situation quite accurately by saying, that he is *doing*

Chemistry, or, it may be, *doing* Physics. He had better be learning the conditions under which he lives, irrespective of scholastic pigeon-holes. No doubt, that feeling has prompted the new syllabus for the subject "General Elementary Science" issued by the University of London, and that for the subject "Elementary Physiography" in which the Science and Art Department of South Kensington hold examinations. The requirements of both these bodies are met, I hope, though somewhat indirectly, in this course of "Natural Philosophy," while they were roughly anticipated in the earlier book. It appeared to me that independence of treatment was not only desirable in itself, but was probably invited by these authorities. With this feeling I was glad to respond to a suggestion that I should write this book.

I have to thank my colleague, Mr. F. Collins, M.A., for helping me along the well-beaten track of chemical rudiments in Chaps. VIII. and IX. The work has been so often done, that it requires no little courage to undertake it afresh, and I am under great obligations for the relief afforded. In the last chapter, I have largely utilised the matter of a chapter in the book mentioned above, and, for permission to do so, I am greatly indebted to the courtesy of Messrs. Longmans, Green, & Co. To Mr. A. W. Brown, B.A., I owe thanks for the diagrams.

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ELEMENTS OF NATURAL PHILOSOPHY



CHAPTER I

OUTLINE OF COURSE

INTRODUCTORY STATEMENT

THE subjects to be treated in the following pages, namely, physical and chemical events, are constantly coming under our notice, though we may not be in the habit of regarding our knowledge of them as forming part of Science. Such occurrences as the boiling of water, the burning of coal, and the action of machinery may arrest the notice without stimulating the intelligence, and without giving rise to reflection. It is only when we begin to seek for the causes of events, and to compare events with one another, that we enter on a scientific course of inquiry.

Many things which are of frequent occurrence are not easily explained. They are so familiar that they do not arouse curiosity, and an explanation is not called for. It is with less common events, as a rule, that the search for causes first begins; but the wish to know the reason of unusual occurrences soon grows into a desire to find an explanation for every event. An attempt to understand the many changes which take place around us, and to arrange in some sort of order the great variety of objects by which we are surrounded, gives rise to the sciences of Physics and Chemistry. Yet it is important to remember that the investigation of changes and the arrangement of objects, if fully

carried out, would make up between them much more than the sciences of Physics and Chemistry can include.

Every branch of science or systematic knowledge is concerned either with the *changes* or with the *states* or *conditions* of objects. When we attempt to investigate any kind of change, so as to understand why it has taken place, and under what conditions it will take place again, and also to learn in what manner it is connected with these conditions, we are engaged in the study of a science. But as the aims of the inquiry and the forms of procedure may differ widely, it is convenient to follow the several sciences separately, and to give distinguishing names to the several occupations into which the study of nature may be divided. Just as there are many ways of studying changes, many sides, in fact, from which they may be observed, so there are many sciences of change. **Physics**, with its branches of Dynamics, Heat, Electricity, Light, Sound, etc., dealing with various familiar changes among inanimate bodies, and **Physiology**, concerning itself with changes in living objects, are prominent among them.

Again, **Chemistry** is a science treating of the constitution and reactions of inanimate matter, while Zoology and Botany are confined to the classification and structure of animals and plants respectively. And the arrangement of objects around us may take various forms, according to the purpose we have in view, whether it be to show *what they are made of* and how they can be distinguished from one another, or, on the other hand, to indicate *what they can do*, how they will behave, or how they are connected with or related to one another. And the pursuit of these various branches of knowledge has in each case a distinctive name.

Now there is one important feature which distinguishes the knowledge embodied in any kind of science from that which makes up the common stock of human experience. It is, in the first place, more accurate. As far as possible it is also *quantitative*, that is, some measurement of the object or the change in question is attempted, and it is this effort to measure and compare everything in its province which is the distinguishing mark of scientific procedure.

Knowledge, too, which may be widely and even universally applied is the desired end of scientific training, knowledge which may have been drawn, it is true, from the study of single and isolated instances, but is valued for its *applicability to all instances and all occasions*.

ILLUSTRATIONS OF THE AIMS OF SCIENTIFIC RESEARCH.

Changes in the position of bodies—the distinction between their states, whether in the solid, liquid, or gaseous form—differences in size, appearance, and density—variations in temperature—changes which occur when certain kinds of matter are brought into contact with one another—these are among the first things to be noticed, classified, and measured.

But a change in the position of a body cannot be perceived directly. Other things have to be noticed at the same time. A movement in a given object would not be apparent but for difference between its own condition and that of surrounding bodies. It is often difficult to decide when a vessel begins to move out of harbour, unless your observation includes the vessel together with some fixed object. Movement cannot be detected except two bodies at least be under observation.

Here we come in touch with a fact which is universally true. By recognising its truth the student is able to make a start in arranging all the possible modes and kinds of motion in classes, and he may then begin to measure and compare rates of motion.

Again, it is not enough to arrange objects under the three classes—*solid*, *liquid*, and *gas*. More information is to be sought. There are degrees in the solid state, varieties, too, of liquids and gases. A piece of flint is harder, or more distinctly a solid, than a piece of cork. Water is more liquid than honey. It is necessary to find out the property which is denoted in each case by the names solid, liquid, or gas, to ascertain what it is which underlies the common and unreflecting application of these terms. Not only is it important to know whether a body is solid, liquid, or gas, but what is the real difference which gives rise to our superficial distinction; how we can decide in case

of doubt, and, if possible, what is the reason of the difference should be learnt. With these aims before us we begin the systematic study of the properties of matter.

As soon as a knowledge of mere distinction in size is found to be inadequate for practical wants, the comparison of sizes becomes necessary, and this implies **measurement**. It is not always enough to know which is the larger of two books, or two boxes. It may be necessary to measure the length, volume, or heaviness of an object, and then we go through a process which is applicable to every kind of object, and likewise to every kind of event in inert nature. That is the process of measurement, one which never varies in its methods and principles.

Into all branches of knowledge, measurement, or the comparison of quantity, enters in some form or other, while in some it is paramount in importance. The principles which underlie the operation of measuring are best and most easily learnt in connection with the dimensions and density of bodies.

With regard to changes of *temperature*, and in events of *chemical origin*, it is especially true that measurement is almost everything. The measurement of the quantities of matter chemically engaged in combining with one another gave rise to the modern development of Chemistry, and constitutes its mainstay. It is one thing to know that coal burns, it is another thing to know that 12 parts, by weight, of carbon require 32 parts of oxygen for complete combination, and that the act of combination is accompanied by a very large and determinable alteration of temperature.

Indeed it is the addition of information of the kind here indicated that distinguishes an item in the ordinary round of experience from the directed and orderly investigation of science. And a knowledge of the quantities concerned in the act of burning, or an understanding of the extent of the thermal changes connected with it, does not merely make our information about that or any other chemical change more complete. It forms part of a *general system of observation*, by means of which great generalisations and theories have come into existence. It is connected with ideas about **atoms** and **energy**. Our aim

will be to follow the course along which discovery has travelled and comprehension grown wider and wider, and to learn to discriminate between scraps of information and systematic knowledge.

THE PROVINCE OF PHYSICS AND CHEMISTRY.

It may be again laid down as above question, that both of the sciences of Physics and Chemistry are mainly based upon the accurate observation of *events or changes*. Now most of what we know, even about things as they are, has been derived from watching things *while they are undergoing change*. We have had to learn how or what they are now, by noticing how or what they were previously. And all the events which take place, while a change is in progress, require to be watched, and, as far as possible, measured.

It was stated at the outset, that one characteristic of all scientific work is the search for **causes**, and this means finding out *what has gone before*. The cause of a chemical or physical event, just as of any other change, is nothing but a similar kind of occurrence which has preceded it or been joined with it. Nothing takes place by itself. Every event is joined with others in an endless series. The movement of a train—the action of the engine—the pressure of steam—the burning of coal—the formation of coal through the work of plants—the dependence of plants on the sun for their life—illustrate how far back such a series may reach. In other words, these two branches of Natural Science or Knowledge of Nature contain information about the present state or condition of inanimate objects, the changes these objects may undergo in the future, and the changes they have undergone in the past.

Many familiar events and many well-known facts will be described and discussed in a manner tending towards a certain end, namely, the acquisition of a *connected body* of knowledge. Hence it will be found that facts are not simply stated by themselves, nor given in any order, but they are described as far as possible in such a way that their *connection with one another* may be perceived, and so that they may form an introduction to more

complete and more accurate knowledge, or even prove a stepping-stone to **research**, that is, an attempt to add something new to the store of human knowledge.

The plan or order, according to which the subject is treated, is one which experience has proved to be the best. It is not a course which the beginner would be able to create for himself. Indeed, a beginner cannot very well be in possession of a plan of work. He must be content to receive it from others, and he must follow it patiently, with the certainty that in the end he will gain much more by following the guidance of his teachers than by following his own inclinations, however praiseworthy and good in intention they may be. As a matter of fact industry must be directed and controlled or it will not be effective.

It is customary to give to the student a definition of the subject which is about to occupy his attention. Yet definitions should properly come at the end of a course, for they will be understood there better than at the beginning. It may be stated provisionally that this introductory course of science or **Natural Philosophy** is intended to prepare for the more systematic study of Physics and Chemistry. Its object will be to furnish the student with an outline of two great conceptions which dominate every branch of physical science, namely, the principle of the **Conservation of Energy** and the **Atomic Theory** of the constitution of matter. With this object in view, the various kinds of change which are to be observed, and the various properties of matter which are to be investigated, will be described. The different forms of *quantity* which need to be measured, and the principles of *measurement* will be pointed out. The several forms and transformations of *energy* will be indicated, and an outline of the classification of the innumerable forms of *matter*, in accordance with the theory of a limited number of elementary substances, will be given.

The treatment of the subject will be practical throughout, and the illustrations of the various branches of measurement and observation which are selected may be followed and confirmed by the student himself in the laboratory. In addition, some stress will be laid on the direct application of laboratory results

to a wider region of observation, namely, to that knowledge of the earth, its movement and prominent features, which constitutes the material of the science of **Physiography**.

ILLUSTRATIONS OF THE PROVINCE OF PHYSICS AND CHEMISTRY.

THE FALL OF A BODY TO THE EARTH.

A body falls to the ground unless it is supported. This fact is so familiar, and is impressed on us at such an early stage, that it appears absurd to take the trouble to describe it in words. But it is worth mentioning, as an instance of how easily we are contented with knowing part of a change, instead of trying to find out all that is to be learnt about it. That a small body near the earth moves towards it is a better description. But it will be still better to say that all bodies move towards the earth if they are not already touching it. The change may occur anywhere, and at any time, in the case of any body near the earth.

But there still remains something to be said as to the manner in which that movement takes place. In what *direction* and at what *rate* does the body move? The direction is always the same, that is, the shortest path is taken, and this is readily and directly perceived. But the rate cannot be directly watched because it is, in most cases, too rapid. Special modes of observation will have to be adopted, at a later stage, to learn about the rate.

When the manner of the motion, *i.e.* the rate and direction, have been learnt, one part of our investigation is completed. But another still remains. It is possible that other events may occur at the same time as the body falls, and it is possible that they may be connected with one another. These are matters which will have to be inquired into, if the change in question is to be fully understood.

THE SWING OF A PENDULUM.

It is clear that we have in the pendulum an instance of a body, which is trying to fall to the earth, but is prevented from

doing so by its attachment. But the first half of the movement, which follows when the pendulum is disturbed from its position of rest, is the only part of the change which corresponds with the fall of a body. As soon as the bob of the pendulum has reached its lowest point, a rise follows. The fall is succeeded by an upward movement of equal extent, as of a body being thrown away from the earth's surface. This in its turn is followed by a fall and rise in the opposite direction. The motion, with its fall and rise with regard to the earth and its reversal of direction, continues until friction at the point of support, or the resistance of the air overcomes it. When once started the change in the position of the pendulum would be incessant but for friction, though the range of movement is small and the same path is repeatedly traversed.

Clear observation of the swing of a pendulum reveals the fact that *the rate of movement varies*. It is at its greatest when it is passing through the position at which it rests. At the farthest point of its swing on either side the movement momentarily ceases. It becomes slower, stops, and is then reversed in direction.

There is, however, another fact of importance to be noted in the movement of a given pendulum. All its swings *appear to occupy the same time*. It will be impossible to detect, by any method of timing which you may employ, any difference in this respect between consecutive swings. It is not asserted that this is absolutely true. More refined methods may show that they are not all absolutely alike in duration. This remains to be seen. But to ordinary observation they will appear alike.

But this similarity in time, which is usually described by saying that the *period* of oscillation is constant, does not extend to all pendulums. It holds true of the same pendulum alone. Each pendulum preserves its own period unchanged, but the period varies in a marked manner with the length, becoming slower as the length of the pendulum increases.

The observation of this familiar event is not complete until its connection with the dimensions and shape of the pendulum is ascertained. Even when this has been done, the possibilities of

learning more about the manner in which the motion takes place are not exhausted, until it has been tried under the most varied conditions of place and time.

PRACTICAL WORK.

Apparatus Required.—Small cast-iron or lead ball weighing from $\frac{1}{2}$ to 1 lb., with a small hook attached for suspension, fine strong twine or thread. Watch with seconds-hand, or metronome.

Suspension is best obtained by tightly clamping the twine between two small blocks of wood, using the clamp of a retort-stand, or ordinary iron clamps.¹

By clamping strips of wood to the edge of a table, or a shelf, supports for the pendulums are conveniently obtained, and the actual suspension may be from a small rivet or peg driven in the wood, though the method of clamping permits a variation in length to be most conveniently carried out.

OBSERVATIONS TO BE MADE.

1. **The time of an oscillation does not vary as the amplitude alters.**—Ascertain the time of a single oscillation by observing how long is taken by about 30 of them, and then dividing the total quantity of time by that number. Then vary the amplitude, that is the distance through which the pendulum swings, and find out if any change ensues in the period, that is, in the time of swing.

2. **The time of an oscillation is altered by a change in the length of the pendulum.**—Vary the length of the pendulum so as to be in the ratio of the numbers 1, 2, and 4. Compare the times of swing for these different lengths. Length is to be measured from the point of suspension to the centre of the “bob.” Note that the times are not related in such a simple manner as the lengths.

3. **The time of an oscillation is quite independent of the quantity of matter serving for the bob of the pendulum.**—This may be demonstrated by suspending bodies showing a marked difference in weight, and measuring the period of oscillation when the length of the pendulum remains unaltered.

Make a record in a tabular form of the facts observed under the above three sections.

Note that in these experiments we are dealing with what is called a *simple pendulum*.

¹ Sold at about 10s. a dozen, and very useful for many purposes in a Practical Course of Physics.

THE DIFFERENCE BETWEEN A BODY AT REST AND IN MOTION.

The previous illustrations have taught us, that even the simplest changes may be looked at in several ways, and also, that it is best to pay attention to one part of a change at a time. But there are few changes which are so easily described as these were, and still fewer which can be so completely described. It is necessary, for example, to be satisfied for the present with a very incomplete description of the manner in which a body at rest differs from one in motion. What the difference depends on, how much is due to the body itself, and how much to its motion, can only be grasped after many careful observations have been made. It will be enough now to demonstrate, that a great difference exists.

Experiments.—1. A piece of thin paper stretched over the wire ring of a retort-stand will support a fairly heavy body, a bullet or an ounce weight, when carefully placed on it, but the paper will be pierced if the body be allowed to fall on it.

2. A thread which is strong enough to support a weight may be broken by allowing the weight to fall, or by putting it in motion.

3. The extension of the spring of a spring-balance, by a body attached to it by a string, is increased by allowing the body to fall through a short distance.

In each of these experiments a new property is added to the body by its motion. It is able to do more *work* than it could before. The movement of a pendulum exhibits the same fact. When it has reached the lowest point of its swing, the motion then possessed by the weight, or bob, enables it to raise itself, through a distance equal to that by which it was first displaced from its position of rest. In the act of falling *it gains something*, which enables it to rise again through an equal distance.

This, too, may be added, that the greater the rate of motion, the more the body endowed with motion gains in ability to *do work* or *overcome resistance*, and numerous illustrations of this will suggest themselves. A further treatment of this subject forms one of the most important parts of Physics, for most physical changes may be considered as examples of work being done, and the most prominent agents of work are moving bodies.

THE BOILING OF WATER, AND MELTING OF ICE.

These two occurrences belong to another class, but they are not entirely unconnected with events of the class just described.

Apparatus.—A flask, thermometer, gas-burner, stand, and wire-gauze. Also a beaker and ice.

Experiments.—1. Fill the flask with water half-way up the neck, and mark the level by tying a piece of thread round the neck. Note that as the water gets warmer it expands.

2. The change may be made much more marked by fitting a glass tube to the flask by means of a cork. The flask is filled with cold water, so that when the cork carrying the tube is pushed in the neck, the water rises some distance up the tube. On warming the water in the flask, the change of volume is now more easily seen.

Compare this apparatus, and what it shows, with the thermometer consisting of a bulb and tube of very fine bore, and what it shows.

3. Use the flask partly full of water, insert the thermometer, and heat to boiling-point. Note that while the boiling continues no further expansion of the mercury ensues. Its level continues steady. Either the expansion of mercury ceases at a certain point, or the water ceases to get hotter, although it remains in contact with the source of heat.

4. Break the ice in small pieces and pack them in the beaker round the thermometer. Notice that an event of the same kind as the last takes place. The mercury contracts as it is cooled by the ice, then remains steady.

Both of these events, the melting of ice and the boiling of water, may be described, names may be given them, and the words *temperature*, *melting-point*, and *boiling-point* may be used, but information of this kind will not help us much towards understanding them. A wider range of observation and experiment must be first undertaken, and this subject will occupy much of the time of the student of Physics.

But without going too far, this much may now be said: that the steam formed from the water, and also the water formed from the ice, have gained something new, in much the same way as a body in motion has acquired something not possessed by the body at rest. The comparison becomes closer when it is recollected—and no experiment is needed to demonstrate this fact—that two bodies when they are rubbed together become sensibly warmer.

Chemical Changes.—Chemical changes form a class by themselves. They differ from others in one important respect. Substances which undergo a change of this kind are no longer recognisable by the sense of sight. Their appearance is altered, and it is this alteration in appearance which confers upon chemical events their most obvious character, though it is not their sole feature.

Illustrations.—1. The burning of a candle is a chemical change. The material of the candle becomes an invisible gas for the most part.

2. Copper powder¹ when dry is weighed and then placed in a piece of hard glass tubing. After being heated by a bunsen flame for some minutes it changes in appearance. It has become black. On weighing this black substance it is found to be heavier than the copper from which it is formed. There is something added to the copper. It has been proved by various experiments that something was added to the candle in the act of burning, and that the two changes are similar in respect to the substance added (oxygen by name).

The rusting of iron after exposure to the air is an instance of a similar change.

3. Heat the black substance just obtained with some weak sulphuric acid, and some unchanged copper also with similar acid. A blue liquid is obtained in each case, and these when evaporated each yields a blue crystalline body.

4. Leave a bright piece of iron in the blue liquid for some time, the copper will reappear upon the surface of the iron.

5. Place a piece of bright copper in a solution of mercury nitrate. The copper becomes coated with mercury.

Such a change might readily give rise to a belief in the transmutation of metals, and from such changes did the belief first arise. But if we attend to the liquid itself, and not to the copper, the explanation appears.

Dissolve some mercury in nitric acid, and then place a piece of copper in the solution. The mercury, then dissolved and lost to view, does but reappear on the copper. There is no transmutation here, but certain indestructible bodies, which have temporarily lost their more prominent qualities, regain them and reappear.

The conclusions to be drawn from these results are plain.

Substances may be changed beyond recognition, and yet may present all their properties again unaltered. However deeply rooted the change may seem to be, there must be something

¹ May be easily prepared by placing zinc in a solution of copper sulphate.

unaffected in every case, something in the nature of the substances which prevents *complete loss of identity*.

It is also important to remember that no substance is changed by itself. Other events go on in other bodies at the same time. No satisfactory knowledge of the phenomena, or of the products of flame and fire was gained, until attention was directed to the substance, air, and the effects produced in it during combination.

That there is a distinction to be drawn between chemical and other changes is clear, and this distinction is important; but it is equally important to recognise, that there are many respects in which they are alike, and this resemblance will be pointed out more fully at a later stage of our course.

SUMMARY OF RESULTS.

Any of the illustrations which have been given will help us to understand, that even a part of the surroundings of a given change may be enough to afford an *explanation* of it, and that, when all its surroundings have been included in our observation, there is nothing more to be learnt which can be described, strictly speaking, as explanatory. All that can be learnt of any change is achieved by the accurate observation of *all its circumstances*. By paying attention to all that precedes it, and all that follows it, we are doing all that is possible. Inferences may be made and conclusions drawn, but the certain and infallible knowledge of nature is based wholly on **observation**. Agents of change or causes of events must be directly perceived, and fictions must not be imagined or invented in order to save the trouble of looking for the reality.

Definitions.—**To observe**—to learn by the exercise of the senses, mainly sight and touch.

Inference—an effort of the reason to go beyond direct observation. Experience of what has previously happened under similar or like circumstances enables us to foresee what will happen again, or what must have happened on a given occasion. But inference is also exercised whenever the mind is occupied in reasoning about, or in forming a judgment upon, what comes under observation. It is a mental process often described as “guessing.”

A PRELIMINARY CLASSIFICATION OF CHANGES.

Every change observable in an inanimate body must belong to one of three classes—

1. Change of Position.
2. Change of Form.
3. Change of State.

The last kind of change is the widest and the most difficult to understand. A great variety of events comes under the heading of change of *state*. Water changed into ice, coal passing away as a gas, a filament of carbon glowing and heated by an electric current, and the momentum acquired by a body in motion, are instances of change of state.

Change of *position* is the simplest kind of change to be noticed. Yet its simplicity does not always make it easy to explain. It will be necessary first of all to understand what is meant by position, but if we take it for granted, that position with regard to the surface of the earth is understood, it will be easy to understand, that change of position may always be described as an alteration in the distance between two bodies. It is readily and directly observed, and no simpler kind of change can occur. The movement of living things and that due to machinery afford the most prominent examples.

It is clear in every case that two bodies, or two positions, at least are always needed for its detection. Sometimes a rough value of distance is rapidly estimated by the eye, but in doubtful cases more exact measurement is necessary.

Changes of *form*, such as occur when a body expands or contracts, or when it is altered in shape, are closely akin to change of the first class, for we have only to fix our attention on the parts of a body, and it becomes clear, that any kind of alteration in the form of a body, as a whole, is merely a change in the relative position of its parts.

Now it may be stated, that all changes are *connected with matter*. They are made *perceptible by means of matter*. Nothing is known to take place outside ourselves except it be

through the agency of material bodies, and all the innumerable events occurring in nature may be classed either as changes in the position, form, or state of material objects.

ILLUSTRATIONS OF DIFFERENT CLASSES OF CHANGE.

The daily experience of alternation of light and darkness directs attention to a movement of the earth with regard to the sun. No impression of change can compare with this in importance and vividness. The only movements on a large scale, which are noticeable on the surface of the earth, are those of water from a higher to a lower level, as seen in rivers and streams, the tides apparent at sea, and the movements of the atmosphere. Compared with these, the movements due to human contrivance are insignificant.

With regard to those instances of change of position which come under our own control and may be made to take place under our own eyes, it may be noticed on most occasions that motion is *directly conveyed from one body to another*. A good illustration is afforded, by suspending a number of hard bodies by strings so as to touch one another, and then allowing the one at the end to strike its neighbour. The movement is communicated, *imperceptibly*, through several bodies in turn, until, when the last body of the series is reached, the motion is exhibited. Many other cases suggest themselves, as showing, that a body moves because another moving body strikes or presses against it.

On the other hand, there are many instances in which the action is not so *direct*. In the movement of a piston under the pressure of steam, the process of transferring motion is not apparent, although there are reasons for inferring a transfer of a simple kind to take place.

The fall of a body to the earth may be regarded as a result of a *previous movement*, by which it was pressed away from the earth, just as the compression of a spring may be followed by a rapid motion and restoration of every part to its previous position, on the removal of the compressing body. The comparison of two instances of the kind here given will often be found instructive.

The movement of a piece of iron, while a magnet is moved in its neighbourhood, or of a light body towards one which is electrified, may also be brought to mind in this connection.

Changes of form are commonly found to follow an alteration in temperature. A body usually becomes larger when heated, and smaller when cooled, but these changes, though occurring everywhere, are less striking than the deformation of bodies under pressure. Whenever one body presses on another, the body which suffers the pressure either moves, or is deformed or strained. It may be, that the material undergoing the strain is of such a nature as to show no outward indication of this state, and in that case there is no change of form. But in many cases it is perceptible and measurable. In structures, such as houses or bridges, the object is to prevent the change of form and the motion which often follow on pressure, by using a suitable arrangement of non-yielding material.

Those changes which do not come under the head of changes of position or of form are classed together, for convenience, as **changes of state**. It must not be forgotten, however, that such a description does not add much to our understanding, though it may help us to arrange events in some kind of order.

A body raised from the surface of the earth and maintained in that position is also changed in *state*. And it will often happen, that change in position coincides with change of state. It differs from a body on the surface of the earth. It is able to return, and to do work in so doing. A head of water, a compressed spring, a compressed gas, a hot body, a wire conveying a current of electricity, an electrified body, a charged plate of an accumulator, serve to show, that *capacity to do work or effect changes* may be acquired by a body in a great variety of modes.

THE MEANING OF THE TERM STATE, AS APPLIED TO MATTER.

A description is wanted of the meaning to be borne by the term *state of matter*. After what has been laid down in the

previous section about the various kinds of change, it is natural to turn our attention to those objects, in which, or by which, change is manifested to us. We shall find on doing so, that a knowledge of the various kinds of change must be acquired, before the meaning of the state or condition of matter can be understood.

It may be laid down as universally true, that changes cannot be understood apart from the material bodies which exhibit them, and, likewise, that matter cannot be understood apart from the changes which may take place in it. In other words, the two great facts of external nature are **matter** and **change**, and they are so bound together that they can never be separated even in thought.

The accuracy of this statement is borne out in any attempt to describe accurately what is meant by the condition or state of a body. It is immaterial, whether we are talking of the states commonly spoken of as solid, liquid, or gaseous, or have in our minds the condition of a body with regard to temperature, electrification, energy, or other phenomenon. Every state of a body, excepting only its dimensions, is perceived and estimated by some change which that body produces *on others*, or else by the change which other bodies produce *upon itself*.

To distinguish a solid from a liquid, it is necessary to find out how the substance in question behaves with regard to other bodies, or, what is the same thing, how other bodies affect it.

To find out if a body be at a high temperature, or if it be electrified, we watch its behaviour with regard to other bodies. The pressure of a heavy body upon a liquid has a different result from that of a heavy body upon a solid. The resistance of the solid to deformation distinguishes it from a liquid which readily undergoes change of shape. To find out about the temperature of a body, we have, generally, to watch the extent to which it causes the mercury in a thermometer to expand or contract.

Matter and changes in matter together form the whole field of investigation for Physical Science, and it is important to try to realise this two-fold aspect of our subject at the outset.

THINGS WHICH HAVE THE FIRST CLAIM TO BE MEASURED,
AND THE MODE OF MEASUREMENT EMPLOYED.

Distance.—The measurement of distance or length is always one of the first operations to be undertaken in practical work, not only because it is the simplest to carry out, but also on account of the fact that an estimate of length enters into *almost all later measurements*. It is appropriate, therefore, to mention length, or distance between two marks or objects, as the first thing to be investigated.

It will be found that the same principle controls the measurement of all lengths. No matter whether the distance is very small, the thickness of a wire for example, or so vast as the distance of the earth from the sun, a **standard** wherewith to measure is a necessity. Widely as these two operations may appear to differ, there is no real difference, except in the method of applying that standard which is a necessity for both cases.

Direction.—When the methods of measuring length have been practically followed, it will be necessary to learn what is meant by direction, and how it is defined or described. It is known that a knowledge of direction, aided by that of distance, is required before the position of a given body can be described. The position of a town, if not known, is sufficiently described, when it is said to be a certain number of miles in a certain direction, starting from a known position. The position of a tree in a field may be similarly described, by a distance in a known direction from a given point.

But it will be noticed that some starting-point is always required, if real information about direction is to be conveyed. The need of a **starting-point** may be associated with the need of a **standard** in measuring length. The length to be used as a standard or unit must be a *known value*, and the point by which direction is defined must be a *known point*. It must be possible to refer to the starting-point, just as it is essential to be able to refer to the standard length. These facts give an indication of the limits which are fixed to all measurement. We can never get beyond *comparing* things with one another.

Position.—It will be seen that *position* has much in common with *direction*. Indeed direction and distance combined are enough by themselves to give full information about position. And once having a definite knowledge of position, you will easily understand what is meant by motion, or *change* of position.

But position is not quite so easy to describe as it may appear to be. Its description assumes a thorough grasp of the fact, that nothing can be estimated or measured except **by comparison with something else**. A given position can only be defined by referring to one other position at least, and this is supposed, for the time being, to be fixed and unalterable.

Almost all the positions, about which we are concerned, are upon the surface of the earth, yet the earth itself is known to be in rapid and involved motion. It is impossible, therefore, to speak of *absolute position*, though position upon the surface of the earth is easy to describe. For most purposes this is all that is wanted, but it is important to understand, that position so described is only *relative*, and that motion, too, is always relative will have to be realised in treating of motion.

Surface.—Every solid body is *bounded*, or separated from space, by one or more surfaces. A surface is that which separates one portion of space from another, or constitutes a limit to any portion of space. But it is clear that we cannot deal with surfaces, except so far as material objects present them to our observation. All practical knowledge of surface is derived from observation and measurement of the exterior of solid bodies. And since it is necessary to measure all quantities by comparison with a standard quantity, of the same kind as that being measured, we shall become best fitted to understand what a surface is by learning to measure it. The magnitude of a surface is spoken of as its **area**.

It must not be forgotten that a surface does not really belong to the body which presents it. It does not partake of its nature. Surfaces differ in shape and size, but they have no other kind of difference. Just as we are dependent upon material bodies for our perception of length, so are we dependent on them for our ideas of surface. Yet in both cases it is space that we are deal-

ing with, though we can understand nothing about space, except by means of the bodies which are scattered about in it.

Volume.—The conception of volume resembles that of distance and surface in being part of our knowledge of space. It is the quantity of space enclosed by a surface, or by a combination of surfaces. In speaking of the volume of a given body, we refer to the quantity of space it occupies, that is, to its *size*. We find in connection with volume, as with other quantities, that **the process of measuring alone leads to exact knowledge**. And the conception of surfaces, as the limits or boundaries of space, is a necessary foundation of that knowledge. Just as lines are to be regarded as the boundaries of surfaces, surfaces themselves serve as the boundaries of volumes.

Ideas about lines, surfaces, and volume make up between them all that is definite in our knowledge of **space**. And to understand these elements in our conception of space we depend upon material objects. Space is intelligible only through matter, and both space and matter are two fundamental things which enter into every item of positive knowledge, and therefore demand to be considered in the first place. It is quite true that we may think about, and discuss, a volume, without imagining it to be filled by a material object, just as a surface may be considered and estimated, without attention being directed to the body presenting it, but the beginning of knowledge on these subjects, and its end, too, lies in matter.

THE PERCEPTION OF CHANGE.

It is only after some acquaintance with the meaning of distance, volume, and direction has been gained, that it is possible to enter into any discussion of **change**. There is a sense of something antagonistic to change in our thoughts about space, and the operations by which distance and direction are investigated confirm the view, that space is something in itself *invariable*, though it forms the medium in which change presents itself.

Now the changes perceptible in space, which must first occupy our attention, are those alterations in the disposition of bodies

which are found out by successive measurements of distance. Even the more prominent changes in the relative position of bodies are made known to us after a rough process of measurement by eye. An alteration in the distance between any two bodies is an instance of the **simplest kind of change**, namely, **movement**.

It will be noticed, that in the perception of movement we are conscious of a new idea, a new item of knowledge, and that is **time**. For the recognition of movement it was said, that successive measurements of distance were necessary. Now the word *successive* in itself conveys the idea of time.

Time, like space, is one of our most fundamental conceptions, and it enters, like space, into all our observations and feelings. On this very ground, we experience so great a difficulty in putting our thoughts about it into words. No object can be thought of, much less observed, except as existing in space, and as having some position in space. In the same way as **space** is the something, which comes into our minds as soon as we perceive distinctness or separateness in bodies, or as soon as we realise that we are surrounded by *individual objects*, existing apart from and independent of one another, so do we find it necessary to invent a something called **time**, to express our consciousness that *events have an order and a separation from each other*.

Material bodies have a distinctness and isolation in space, that is, *a position*. Changes in those material bodies have a distinctness and isolation in time, or, as we may express it, events have *a sequence or place in time*.

Hence it is, that time is the medium in which we consider change to take place, and that time and change are so much interwoven in our minds as to be inseparable. It would be possible, indeed, to remove the word *time* from all our descriptions of nature, and to substitute for it a term relating to change, **for every change has to be compared with a standard change which we call a second of time**. That the duration of any change is measured by comparing it with the standard of duration, is another mode of expressing this fact.

Time, again, resembles space, in that we cannot conceive any

limit to it. They are both capable of indefinite exploration. It is impossible to imagine a limit to space, and equally impossible to understand a beginning or end of time. Nevertheless we are concerned in all investigation with a limited space and a limited time. Everything that we know about space or time is gained by measurement carried on within limits, that is, our knowledge is relative.

Moreover, space and time are intimately connected with one another. Time being in reality an aspect of change, and change being in its simplest form always an alteration in position, it is clearly difficult to separate these two conceptions completely.

It has already been stated, that a similar tie connects space with matter, and we have therefore **three fundamental conceptions** which underlie all our thoughts, all our theories, and all our researches into nature. **Space, Matter and Time** are the three fundamental things with which physical science deals, and every item of knowledge must bear some reference to one or other of them. Every act of measurement, whatever may be the complexity of the quantity measured, must therefore consist directly or indirectly of **a measurement of one or more of these primary quantities.**

DIFFERENCES IN THE KIND OR QUALITY OF MATTER.

Inasmuch as differences in the kind or quality of matter will form part of our inquiry, it is appropriate to state here the main lines along which this inquiry will be directed. So soon as observation, even of a superficial character, is turned towards the great variety of substances within its reach, an important distinction has to be drawn, between bodies which are *homogeneous* and those which are *heterogeneous*.

Such things as water, air, bronze, and silver are alike in all their parts, so far as direct observation can inform us. However carefully they are inspected, each individual substance preserves its own special properties *unchanged in all its visible parts*, and for that reason they are said to be homogeneous.

Those bodies which do not exhibit this *even and unvarying*

distribution of the same characters throughout their parts, belong to the class of heterogeneous substances, but as such they will not often occupy our attention.

The chemist is more commonly concerned with homogeneous bodies, and if he has to deal with those which are heterogeneous, or a mixture of distinct substances, he proceeds to a separate study of each of the different components which make up the heterogeneous whole.

It is found, that in most cases the visible homogeneity does but hide an invisible complexity, that the apparent sameness and oneness, existing throughout many substances, is limited in degree. As a result of past discoveries and research, these homogeneous bodies are themselves separable into three classes—

1. Substances which are elementary in nature and not further resolvable. **Chemical elements.**
2. Substances resolvable into two or more elements, which have come together in accordance with certain relations as to quantity. **Chemical compounds.**
3. Substances resolvable into two or more elements, which are not associated in the relative quantities characterising chemical combinations. **Ordinary mixtures which are homogeneous.**

The *conditions* under which the combination of elementary substances takes place, the *changes* which accompany it, and the *theories* by which it is explained, constitute the Science of **Chemistry**. This science is prominently occupied in classifying the different kinds of matter, and in forming a scheme of the properties, which confer upon each distinct substance its character and individuality. With regard to compound substances, their composition and the origin of their complexity are sought. The physical properties and chemical behaviour of the component elements likewise form part of that study.

THE RELATION OF MATTER TO CHANGE.

It only remains now to point out some of the more prominent generalisations about the connection of matter with

change. In dealing with change it will be found necessary to consider :

1. **The quantity of matter undergoing change.**
2. **The kind of matter undergoing change.**

When these two things are known, an important step has been taken in learning about change.

It has been said that space, matter, and time always enter into our knowledge of nature. Change, which takes place in space and time, forms a great part of nature, and space and time have, therefore, to be considered as part of nature quite as much as matter.

We shall be expressing the ultimate basis of all scientific investigation if we say that it is resolvable into :

1. **Measurements of quantity of Space.**
2. **Measurements of quantity of Matter.**
3. **Measurements of quantity of Time.**

CHAPTER II

THE MEASUREMENT OF SIMPLE QUANTITIES

GENERAL PRINCIPLES OF MEASUREMENT

Need of Standard.—The foundation of all exact knowledge is measurement, and in order to proceed with that operation, something wherewith to measure is essential. A standard or unit is *always* needed, no matter whether it be an invariable quantity or a change which has to be measured.

When once a standard has been selected, the next step is to find out how many times it is contained in the quantity being measured. In other words, we measure every quantity by means of another quantity called the standard, and therefore in measuring we are only *bringing two things together for comparison*.

Nature of Standard.—It must be carefully noted that the standard quantity must be of the same kind as the quantity which is about to be measured. Distance is measured by bringing *another distance* alongside it, mass is balanced with *another mass*, and time with *another interval* of time. Again, speed must be measured by a *standard of speed*, energy by a *standard of energy*, work by a *standard of work*. Instead of the word, standard, the term, *unit*, will be frequently used, and it will bear the same meaning.

Magnitude.—The estimation, therefore, of the magnitude of a quantity is, in all cases, a matter of determining how many times a quantity of the same kind, called the standard, must be repeated in order to equal it, or, it may be, what fraction it is of the standard. It occurs sometimes, that the quantity to be measured is smaller than the standard, and then we find out, how

many times it is contained in the standard usually adopted. But it will commonly happen, that the standard employed is smaller than the quantities to be compared with it.

Quantity denoted by a Number and a Name.—It will be perceived, that *numbers* necessarily express the results of measurement. Every quantity, as soon as it is measured, is expressed by a certain number, **the numerical value**, together with **a name**, that of the standard employed. A number together with the name of the standard is necessary to express any magnitude.

STANDARDS USED IN MEASUREMENT.

N.B.—It is imperative that each student should have an opportunity of handling a metre scale (or some portion of a metre) subdivided in decimetres and millimetres; a scale with English standards marked; a box of weights according to the metric system, and a set of ounce weights; a cubic decimetre; a cubic centimetre, and a pint measure. Without a personal inspection of these things the student will gain but little from the following description. The description, indeed, should be read, as far as possible, with the objects at hand.

Length.—The common English standards of length are: the *inch*, *foot*, *yard*, and *mile*. They are related in a simple way to one another. Which of these three standards is employed depends upon the distance to be measured. Long distances are measured by miles, short distances by inches, or even fractions of an inch.

Mass.—The common English standards for measuring quantities of matter are: the *ounce*, *pound*, *hundredweight*, and *ton*. Just as in measuring distances, so in measuring quantities of matter, the standard used depends upon the quantity to be estimated. In large quantities, an ounce more or less need not be considered, and so we employ the larger standards, hundredweight or ton.

The standards of length and quantity of matter have been mentioned together, because our use of them in measurement is much the same. The processes resemble one another, and the quantities are of the same simple order. Length and mass are

indeed two of the *simplest* quantities with which we have to deal. There is, however, one other simple quantity, *time*, but its measurement requires much more thought, and involves greater skill in observation than the others. For these reasons it is discussed later.

Metric Standards.—In addition to the standards given there is a *metric* system of measurement which needs our attention. And inasmuch as the principles involved, and the methods employed, are the same, whatever may be the standards adopted, there is considerable advantage in learning the standards which form the system as early as possible.

The basis of this system is the **Metre**, the standard of length. Compared with the yard it is about $\frac{1}{11}$ th longer; speaking more accurately, it is 39.37 inches. Subdivisions of this standard are $\frac{1}{10}$ th, $\frac{1}{100}$ th, and $\frac{1}{1000}$ th of the whole. Multiples also exist, which are ten times, a hundred times, and a thousand times the metre respectively; only one of these, however, is in common use, the *kilometre*.

The starting-point in the measurement of a quantity of matter is the **gramme**, and in order to measure large or small quantities with convenience, it is subdivided by 10, 100, or 1000, and multiplied by the same numbers, as in the case of the metre.

Decimal Scheme employed.—It will be perceived, that the prominent feature of this system consists in the different standard quantities being related to one another, as multiples of ten. It is a *decimal* system. Hence we shall always be making use of decimal fractions in metric measurement, while in our English system, the various quantities are not related in the same manner to one another, though the relation is always a simple one and admits of easy calculation.

The following table will give fuller information on this subject, and will enable the student to compare the quantities in the two systems with one another. And the practical exercises which follow them, if they are carefully performed, will teach much more about the principles of measurement than a text-book can do.

METRIC STANDARDS OF LENGTH.

1 METRE = 10 decimetres = 100 centimetres = 1000 millimetres.

1 DECIMETRE = 10 centimetres = 100 millimetres.

1 CENTIMETRE = 10 millimetres.

Therefore—

1 MILLIMETRE = $\frac{1}{10}$ centimetre = $\frac{1}{100}$ decimetre = $\frac{1}{1000}$ metre, or

1 MILLIMETRE = $\cdot 1$ centimetre = $\cdot 01$ decimetre = $\cdot 001$ metre.

1000 metres is called a kilometre.

Other names are given to multiples of the metre, namely, decametre for 10 metres, and hectometre for 100 metres, but they are seldom used. The kilometre, which equals 1000 metres, however, is a common standard, and is used on the Continent for such distances as would be measured by the mile in this country.

ENGLISH STANDARDS OF LENGTH.

1 YARD = 3 feet = 36 inches.

1 FOOT = 12 inches.

1 MILE = 1760 yards.

Therefore—

1 INCH = $\frac{1}{12}$ th foot = $\frac{1}{36}$ th yard.

1 FOOT = $\frac{1}{3}$ rd yard.

It will be seen that the factors for multiplying and dividing vary in the English system, while they remain the same in the metric system. But it must not be supposed that the metric or decimal system is necessarily the best for ordinary use.

1 METRE = 39·37 inches about.

1 INCH = 25·4 millimetres about.

METRIC STANDARDS OF MASS.

1 GRAMME = 10 decigrammes = 100 centigrammes = 1000 milligrammes.

1 DECIGRAMME = 10 centigrammes = 100 milligrammes.

1 CENTIGRAMME = 10 milligrammes, or

1 MILLIGRAMME = $\frac{1}{10}$ th or $\cdot 1$ centigramme = $\frac{1}{100}$ th or $\cdot 01$ decigramme = $\frac{1}{1000}$ th or $\cdot 001$ gramme.

The only multiple of the gramme which is in use is the kilogramme, or 1000 grammes.

In the English standards of mass: 1 lb. is equal to 16 oz.; 112 lb. make 1 cwt.; and 1 ton contains 20 cwt. These are the standards used for ordinary purposes. In measuring gold, silver, gems, drugs, etc., other standards are employed, and some care is needed in order not to confuse these separate systems.

1 KILOGRAMME = 2·2 pounds about.

N.B.—The spelling of gramme is frequently shortened to gram.

IMPLEMENTS FOR MEASURING.

Weights.—If you go into a shop and ask for a certain quantity of a commodity, you will notice that the shopman employs certain pieces of brass to enable him to give you the quantity you ask for. These objects are called **weights**,¹ and they contain a standard quantity of matter, the pound, a certain number of times, or else a certain number of those fractions of a pound which we call ounces. Now it would be very inconvenient to have the standard quantity indefinitely repeated. If we want, for example, to weigh out 10 lb. of a substance, we do not find ten weights at hand, but we make up the quantity by using three weights, namely 1 lb., 2 lb., and 7 lb.

In other words, there is a simple scheme by which the shopman can make up any quantity from quite a small number of standard objects. Now, if he possesses such standard objects or “weights” equal to 1, 2, 4, 7, 14, 28, 56 lb., that is seven objects altogether, he can make up any quantity from 1 to 112 lb. For example, to make up 75 lb. he will want a 56, a 14, a 4, and a 1 lb. weight. Four weights, in this case, contain 75 units.

Precisely the same arrangement is pursued with ounce weights. Four bodies, 1, 2, 4, and 8 oz., respectively, can be arranged to equal anything from 1 to 16 oz.

¹ The distinction between quantity of matter or mass, and weight, is one which cannot yet be appreciated. It is advisable to put aside for the present a discussion of this important question, with the admission, that no distinction between mass and weight is necessary for practical purposes.

In the laboratory, the **Metric System** is more frequently used, and the gramme, with its multiples and fractions, is employed. A box of weights of this kind will generally be found to possess masses so adjusted, that any number of grammes may be represented from 1 up to 50, 100, 200, or 500, as the case may be. We use for the purpose pieces of brass equal to 1, 2, 2, 5, 10, 10, 20, 50, 100, etc., grammes. You will notice that the number 19 will require four of these pieces of brass ; 37 will also require four ; 40 will require three.

This box of weights may also contain fractions of the gramme, and in that case it is usual to count in milligrammes, or thousandths of a gramme. Twelve objects, either pieces of aluminium or platinum, as a rule, are so adjusted, that any required thousandth of a gramme can be obtained from them. They will need to be equal, respectively, to 500, 200, 100, 100, 50, 20, 10, 10, 5, 2, 2, and 1 milligramme.

Comparison of Box of Weights and Scales of Lengths.—Now, we shall find, when we come to inspect the two-foot rule, or the metre scale, that the implements of measurement are not quite so compact. For example, a metre scale measures any distance from 1 millimetre up to 1000 millimetres, provided it be graduated in millimetres ; but a box of weights which includes a 100-gramme weight can be employed to make up 201,000 different quantities of matter. But, on the other hand, the standard of length can be utilised in measuring any given length greater than itself, by the process of “laying off,” or measuring by instalments. *There is nothing corresponding with this in the process of weighing.*

Attention may be directed to a difference in the mode of **expressing the results of measurement**. If we were using English standards, we might say of a given distance that it is 1 ft. 8 $\frac{3}{4}$ th in., or that a certain mass is 1 lb. 3 oz. In each case we employ *two names* to describe one quantity (it is true they are the names of standards which are connected with one another). An example of a metric quantity would be 1.125 metre, or 6.375 gramme. In this case *one name* is used, and this is an advantage. At the same time it may

be noticed, that the decimal fractions employed are rather cumbrous.

Original Standard Objects.—It is important to be quite sure of one fact, that wherever we may be, and whatever kind of quantity we may be measuring, there must be somewhere *one single object*, from which must be derived the standard we are using, and the similar standards which other people are using. Every pound-weight in this country is a copy, directly or indirectly, of a certain object called the **Standard Pound**. Every scale for measuring length has, in the same way, been copied from a length called the **Standard Yard**. No matter whether the standards we employ are large or small, they have been taken from these standard objects, or from some authorised copy of them.

The same statement may be made with regard to all the implements used in measuring according to the metric system. All measurements of length or of mass, according to this system, are carried on by objects, which have been compared, either directly or indirectly, with the standard metre or the standard kilogram. It is unnecessary to state, that all these standard objects are most carefully preserved. That they should be completely free from danger of change is a matter most seriously concerning the interests of everyone.

MODES OF ESTIMATING UNKNOWN QUANTITIES BY MEANS OF THE STANDARDS DESCRIBED.

Distance.—There is very little to be described in the process of measuring distance. It simply consists in laying one length alongside the other, and judging by the eyesight (or in some cases by touch) whether two lengths are equal. If the standard length is smaller than that to be measured, it is “laid off” as many times as need be along the length.

Matter.—When we come to measure a quantity of matter, *direct comparison* is not possible. We can neither see nor feel directly when two quantities of matter are equal; we have to use an instrument to tell us. The most accurate and most commonly used instrument is the balance.

The Balance.—The balance is simple enough in construction, but the explanation of its action is not very easy. We must be content, for the present, in considering it as a means of detecting *when two quantities of matter are equally pulled towards the earth*. We can estimate this to some extent by our own muscular sense, and some people can estimate fairly accurately. But the balance enables us to decide this point with great nicety. The instrument is constructed in such a manner that the two *pulls* are opposed to one another, and that when they are equal, the beam of the balance is level and the pointer stands at the centre of the scale. We have, therefore, to arrange a sufficient number of weights in one pan of the balance to exactly counterpoise the body to be weighed.

We may describe this in other words. We may say, that we find out the quantity of matter, in terms of a given standard, by making up, out of a number of *adjusted standard masses*, a total mass just equal to that which we wish to measure. And we judge when they are equal, by finding out from the balance, whether they are equally pulled towards the earth. At a later stage, we shall have to give our attention to the manner, in which that pull towards the earth can be perceived and measured.

Coincidence of Marks.—It is important to remember, that direct inspection cannot do more than tell us if things are equal or unequal, and very often it cannot even give that information. The observation of *equality* or *inequality* is all that the senses can do for us. As a rule, this observation consists in finding out by using one's eyes, whether or not two *marks*, points or lines, coincide. It will be found that all measurement ultimately resolves itself into the question whether or not two marks come together.

In the workshop, it is more common to appeal to the sense of touch, rather than that of sight, in testing coincidence. A little reflection will explain the reason. The result is more generally accurate, when we trust to touch in ascertaining whether a fitting is true, though the principle involved is the same as when sight is used.

In measuring *length*, the marks limiting the length are made

to coincide, at some stage or other in the process, with the marks limiting the standard length. In measuring quantities of matter, we are obliged to watch the coincidence of the pointer of our balance with certain marks on the scale of the balance. In estimating *temperature*, it is necessary to see the mark on the scale of the thermometer, with which the upper surface of the mercury agrees.

Most measurements, in fact, whether complicated or simple, are completed when two points are observed to coincide, and, as a rule, the process begins in the same way. Every physical property or quantity that we may want to measure is made, by some contrivance or other, to show itself to the eyesight or touch. Many illustrations of this will be found as we go on.

PRECAUTIONS TO BE TAKEN IN MEASURING LENGTH AND MASS.

Reality of Coincidence.—The first thing to make sure of, in measuring length, is to see distinctly whether two lengths are exactly equal. This is usually done by noting if the marks which limit them do exactly coincide. Error frequently occurs through this coincidence being imaginary and not *real*. The eye must be so placed with regard to the marks that error is avoided. Marks, too, are not always accurately placed on the standard, and they may be so thick themselves as to be a considerable fraction of the length to be measured. On all occasions, also, the marks to be compared should, if possible, come *into actual contact*.

Indirect Measurement.—Many lengths to be measured, however, do not admit of direct comparison with the scale. In these cases, some arrangement of objects must be made, so that the distance to be measured is *transferred*, so to speak, to a position which admits of measurement. Indirect observations of this kind are frequently necessary in connection with areas and volumes. In all cases of indirect measurement, exceptional care is needed.

Adaptability of Balance.—The precautions to be observed in measuring mass are confined, as a rule, to the proper use of the balance. It is the balance which measures for us, and it must be used in a proper manner. We must know, for example, that

two equal masses agree *in equally affecting the balance*. This may be ascertained by obtaining counterpoise with two quantities, and then noticing if the counterpoise is maintained when the masses are exchanged in the pans.

If the counterpoise be not maintained when this change is made, we may still get accurate results from the balance, by using *a third mass*. If, for example, we have three masses, *A*, *B*, and *C*, and we find out, that *B* and *C* when placed successively in the same pan counterpoise *A*, then we may be sure that *B* and *C* are equal masses, though they may be unequal to *A*. In fact we have now obtained exactly *the same results with B as with C*, namely, a counterpoise with *A*, under precisely the same conditions. This manner of using the balance is always the safest.

There should be no need to state, that the weights which have been used must be *accurately summed up*, and yet this is frequently not done.

MEANS EMPLOYED IN THE MORE ACCURATE MEASUREMENT OF LENGTH.

In order to measure length with the greatest accuracy, it is necessary to adopt some device for rendering **small distances more conspicuous** or more easily seen. The limit of accuracy, however, is not always dependent on the *immediate* visibility of two marks, though this is usually the case. There are various means of rendering the marks, which indicate distances, more easy to be seen, and chief among them are the **Vernier** and the **Screw**. But the sense of touch is a frequent guide in determining when two distances coincide.

The Vernier.—The vernier¹ is a sliding-scale attached to a longer scale, and there is a certain connection between the graduations which are found on each scale. Suppose it is intended to render tenths of the divisions on the large scale visible

¹ This description must be followed with the aid of an actual vernier or a model of one. If the student be not supplied with the instrument itself or some substitute, he will find the description difficult to understand.

or readable, then it will be necessary for the vernier to have a distance marked on it equal to nine divisions of the large scale, and this distance must be divided into ten equal parts. The ten divisions on the vernier are now equal to nine divisions on the scale, and it is clear that each vernier division is nine-tenths of the larger divisions.

Now, if the vernier is fixed, with its *first mark* against one division of the scale, it is obvious that the *last division* of the vernier is against another division on the scale, and that this division is the ninth from the first. Now, the second mark on the vernier is a distance one-tenth of a scale-division on the nearer side of the second division of the scale; the third vernier division is two-tenths nearer, and so on; the last division of the vernier is, of course, *a whole division in arrear*. This follows from the fact that the ten vernier divisions are equal to nine scale-divisions.

Now, suppose the third mark on the vernier is made to coincide with any mark on the scale, then a space of three-tenths, or $\cdot 3$, of a scale-division *is left between the first mark of the vernier and the mark on the scale next before it*. If the sixth mark on the vernier is made to coincide with a mark on the scale, then $\cdot 6$ of a scale-division is left, between the first mark, or zero, on the vernier, and the mark just in front of it on the scale.

In other words, we ascertain, what fraction of a scale-division is indicated by the first mark on the vernier, by looking down the vernier scale, and finding out which line on it most closely coincides with a line on the scale. We have to say "most closely coincides," because the fraction in question may not be *exactly* a tenth. It may be a little more or less, by a distance which the vernier does not permit us to read.

Precisely the same method is adopted for reading to twentieths of a division on a scale. But in this case we should need twenty equal divisions on the vernier to correspond with nineteen divisions on the scale; each vernier division would then be one-twentieth smaller than a scale-division, and as before, all that is necessary, in order to ascertain which twentieth the

fraction is, is to look down the vernier scale, and find out which mark *most closely coincides* with a scale-division.

In using the vernier, then, the advantage lies in the fact, **that it is easier to see when two marks come together**, or when they most closely come together, than it is to estimate the fraction of a very small length by inspection. We may perhaps describe it by saying that the vernier *enlarges* the fraction in a certain manner, and makes it *more visible*.

The Screw.—Small distances can be measured very accurately by means of screws, and the screw really does what the vernier does, although they are very much unlike one another. **It enlarges small distances.**

The axis of a screw moves in a straight line when the head is turned round, provided it be firmly held by some substance. The thread, which is a spiral ridge cut upon it, renders it impossible for the screw to move through a body, unless it be turned round, and the circular motion given to the screw is converted by its construction into a movement, backwards or forwards, in a straight line.

The thread of a well-constructed screw, such as would be used in measurement, is carefully cut, so that the distances between any two of the coils are equal. Now, you will see by inspection, that one complete turn of the screw must cause the screw, as a whole, to travel through a linear distance, equal to the distance between two threads *measured in the direction of its axis*, and this is what is known as the **pitch** of the screw. This particular distance may be very minute, its minuteness is limited only by the closeness with which the thread can be cut. On screws used in measurement, this is very close indeed.

Again, suppose the head of the screw be made very large, then, if this large head be turned round once, a large circle is described, while a *very small linear distance* is traversed by the end of the screw. The screw-head is made large enough to show plain division-lines, and so indicate whether the screw has been turned completely round or only partially, and, in the latter case, what fraction of a turn has been completed. And according to

the number of divisions on the head of the screw, so will be the smallness of the fraction of a turn which can be read. This means that we are enabled to read a very *small fraction* of a very small distance.

In all instruments in which the screw mode of measurement is used, a lateral scale is used in order to facilitate the reading. The number of complete turns which have been given to the screw is easily read upon it. The scale has, of course, been graduated by comparison with the pitch of the screw.

MODES OF MEASURING SMALL QUANTITIES OF MATTER.

A mode of estimating very small quantities of matter ought to be given here, because it so closely resembles in principle the means of obtaining greater accuracy in the measurement of lengths. It may be looked on as a process of *spreading out* the matter, though in this case we do not make it more visible. It depends upon the fact, that when we dissolve a small quantity of matter in a liquid, that portion of matter is *evenly distributed* throughout the liquid. Many proofs of the fact could be given, but they need not be described here.

Method of Solution.—One gramme of common salt is not a large quantity, and a thousandth part of it is a very small quantity. It would be difficult, in fact, to estimate by a balance a quantity smaller than a thousandth of a gramme. But suppose we take a gramme of common salt, and dissolve it in a large quantity of water, it is then perfectly easy to take a very small fraction of that water, and we may be certain, that there is present in it a mass of salt much smaller than could be estimated by the balance.

This process of estimating a quantity of matter, by the use of solutions, is very widely adopted in **chemical analysis**. It is only mentioned here, because it is another illustration of how accuracy may be obtained, by distributing the matter to be measured over as large a space as possible, just as, in measuring very small distances, we had to find some means of extending them.

MEASUREMENT OF SURFACE AND VOLUME.

It is not easy to describe what is meant by an **area** or **surface**. The surface of a body is, strictly speaking, its *boundary*, that which limits it, and separates it from the rest of space. It is clear that it no more belongs to the *body*, upon which we measure it, than to the *space* around the body. But it is also clear, that we cannot observe nor measure surface, except upon some solid or liquid body.

Areas.—Quantity of surface must be measured by means of a *standard surface*. The standard or unit surface is called a square centimetre in the metric system. In the English system we measure by square feet, square yards, or square miles, according to the requirement. In the metric system, larger surfaces would be measured by square metres or square kilometres.

The **square centimetre** is the usual standard for the laboratory. It is a surface equal to that of a square, of which each side is one centimetre in length. It must not be supposed, however, that a square centimetre of surface is necessarily in the shape of a square. It may be of *any shape*, and yet be equal to a square centimetre. In the same way, a larger surface is spoken of as being equal to so many square centimetres, though it may be of any shape whatever.

Surfaces are not always easy to measure; they are sometimes so irregular, that it is difficult to compare them with the standard area. A **plane surface**, which is alone capable of direct measurement, is defined by Euclid as being one in which, any two points being taken, the straight line between them lies wholly within the surface; while he describes a surface as that which has length and breadth, but no thickness, and states that the boundaries of surface are lines. The practical test of a plane surface is to try, if it fits, and touches at all points, against a known plane surface; or, what answers the purpose quite as well, ascertain if a straight-edge, when placed against it in any position, is touched at all points.

Volumes.—Volume is the quantity of space enclosed by a real or imaginary surface or surfaces. In measuring volumes, we

need not pay any attention to the *shape* of a body. Bodies of very different shapes may possess the same volume.

The standard or unit of volume in the metric system is a volume equal to that possessed by a cube, each edge of which is a centimetre long, and each surface of which is a square centimetre. On the cube, there are six such surfaces, and twelve such edges. It is called a **cubic centimetre**, or centimetre cube.

Volumes may also be measured by cubic decimetres or cubic metres. The cubic decimetre is also called a **litre**. English standards are the cubic inch, foot, or yard. Volumes are also measured in pints, quarts, or gallons.

MEASUREMENT OF TIME.

Time difficult to realise.—In measuring space in the form of length, area, or volume, and likewise in measuring matter, we have been dealing with things which are *fixed* and *constant*. In forming an estimate of time, we are entering upon a new order of observation. The word **time** carries with it a sense of *change*. And in measuring time, we are measuring change in a certain manner, and treating it as a quantity. But in order to do so, we stand in need of some standard change. It will occur to most people to say, that the standard of time is the **second**, but a clear understanding of the manner in which this quantity of time is fixed upon, is difficult to acquire.

The main difficulty, in understanding time as a *quantity*, arises from that which distinguishes time from length and mass. It does not remain constant and unchanged while being measured. *The measurement cannot be repeated.* That which is being measured has ceased to exist as soon as the measurement is complete. Not so with length and mass; they do not disappear, but submit themselves to *repeated* observation and verification.

Need of Standard of Time.—Now, as a matter of fact, we do not, strictly speaking, *measure time itself*; what we do measure is change, or rather a certain aspect of change. And in order to do so we employ a **standard change**. This is all that is needed, namely, to compare a given change with a standard

change, in respect of that which we call time. What time really is, does not so much concern us as accuracy in measuring it.

Words such as *second*, *hour*, *day*, *week*, *year*, and the phrases *length of time*, *duration of time*, are in constant use. They imply that time may be regarded as a quantity, which may be measured as other quantities have been measured ; the sole difficulty is to fix upon the means of measurement, or the standard.

The Day.—The first recognition of time, as an orderly succession in events, lies in the perception of day and night as alternating. The apparent motion of the sun gives rise to the separation of day from night ; and, further, the height to which the sun appears to rise in the sky determines the season. It reaches its highest point at midday in summer, while in the winter the elevation is considerably lower than in the summer. At night-time, too, the apparent movement of the stars gives an indication of change, and enables us to form an estimate of the lapse of time.

Now, by a process of counting, extending over many years, we should be able to notice, that there are 365 days in each year, if we describe by the word *day* the whole interval from midday to midday, that is, the interval covering the period marked both by daylight and darkness. But by still more extended observation and comparison with records, it would be found that there are $365\frac{1}{4}$ days. A year, then, does not contain a whole number of such periods. From this arises the necessity of giving to every fourth year an additional day. Such a year contains 366 days ; it is called **Leap Year**.

Observations of this kind, however, are far too lengthy for any one person to carry out. Mankind has arrived at the existing knowledge of these facts by observations, extending not only over many years, but over many generations, and they represent the labours of many investigators.

The investigations which have produced this result have also given rise to the knowledge, now familiar and common to everyone, that the change of *day* and *night*, and also of the *seasons*, is due to the movements of the earth. It was for a long time believed, and believed, too, by the wisest men, that the alternation

of day and night, and of summer and winter, was due to the movement of the sun in space. The sun, and the stars too, were believed to move round the earth. We have, nowadays, many reasons for believing that this is not true, and that the sun and stars are comparatively fixed.

There is, indeed, little difficulty in proving that the earth turns round, or *rotates*, and not only does it rotate, just as a top may rotate or spin, it also *moves on*, while it spins. It might be spinning without moving its position, and it might be moving its position without spinning, but we are forced to believe that it does both. It moves round the sun continuously, in an enormous elliptical **orbit**, and the completion of one journey round this path, or orbit, becomes known to us as the completion of a year. One complete turn or rotation marks itself as the period called a day. When the earth has once turned round, a day has elapsed. Two successive sunrises form, roughly speaking, the limits of a single rotation.

Subdivisions of the Day.—But it is not long before we recognise that the period we call a day must be subdivided. We can only do so by making use of some change, which can be made to *repeat itself without alteration*. In past times, the burning of equal lengths of a candle was used to mark equal intervals of time. The fall of the same quantity of sand, or of water, through the same opening was similarly employed. But these methods were soon felt to be too cumbrous to serve the growing want of accuracy.

The Pendulum.—The change upon which we now depend absolutely is the *oscillation of a pendulum or spring*. Most of our knowledge of time is gained by watching the oscillation of a pendulum. And this arises from the fact, that the same pendulum, under the same conditions, oscillates in the same time, that is, it makes each of its movements, to and fro, in the **same period of time**. We possess in this change, namely, the movement of a pendulum, a source of information which is of the utmost importance. Our confidence in the equality of its period of oscillation is based upon the belief, that *similar events under precisely the same conditions will repeat themselves unchanged*.

The isochronism, or equality of time, of the earth's revolution, is confirmed by the fact, that no deviation of the observed times of eclipses from the times calculated on this assumption has been appreciable. In reality, this coincidence is the sole direct proof of successive revolutions being alike.

THE LIMITS OF ACCURACY IN MEASUREMENT.

The relation of a given quantity to the standard employed in measuring it, cannot always be expressed by a whole number, nor can it always be expressed as a whole number together with a definite fraction. For example, a length may not be quite equal to any whole number of centimetres or even millimetres. An area may not be equivalent to any definite number of square inches, or any recognised fraction of a square inch, and it may remain incommensurable¹ with regard to any of the usual standards.

Now, it is always the quantity, said to be *left over* (or not directly comparable with the standard), which makes the strongest demand upon the skill of the observer and the ingenuity of the instrument-maker. By special means, such as have been described, this remaining portion of the standard may possibly be brought within the range of measurement, and its actual or approximate value may then be expressed as a fraction of a whole number.

But as the means of observation, that is, the accuracy with which the coincidence of marks (points or lines) may be detected, grow more and more refined, inequalities may appear where equivalence has been assumed. With the most perfect graduation of the implements of measurement, and the greatest skill in their use, the limit of accuracy is reached. If the marks, denoting the boundaries of the quantities which are being compared in the process of measurement, do not then coincide, and imaginary coincidence cannot be estimated, the results of the process can, so far, only approximate to truth.

On the other hand, it may be mentioned, that the degree of accuracy to be looked for will vary with the purpose in view, as well as with the means available. It will be observed, too, that the greatest accuracy is reached in measuring length, mass, and time, quantities which are simple in character and directly estimated by the coincidence of two points. Areas can never be estimated with as great precision as lengths, inasmuch as coincidence of a whole boundary has to be judged, and volumes lend themselves still less readily to accurate measurement, unless indirect methods are employed.

More complex quantities, needing for their measurement two or more

¹ Unmeasurable,

operations, are necessarily expressed by numerical values, calculated from the numerical values obtained in each of these separate operations. Chances of error in the results are, in consequence, frequently incurred; and, in addition, it is a very common fault, to give to the values calculated a fictitious appearance of accuracy, by a long row of decimals having no correspondence with any fact of observation.

Summary.—Lengths are known to be equal, when the points, short lines or small surfaces, by which they are limited, can all be made to touch at the same time. Straight lines are understood.

Plane areas are only known to be equal, when the lines enclosing them can be made to touch at all points.

Volumes are only known to be equal, when the surface or surfaces enclosing them can be made to touch at all points.

Masses are known to be equal, when they produce similar changes in the same body, or when the same body affects them equally. The converse of these statements does not hold. *Masses, for example, are not necessarily unequal because they act differently.*

Equal times are those in which similar changes occur.

Equal masses and equal times alike are estimated by the coincidence of the marks or sounds which serve to denote the *extent* or *duration* of a change.

The measurement of every kind of quantity is carried on, by first determining, in the manner described, what are equal quantities, and then by ascertaining how many quantities equal to a standard are equivalent to the unknown quantity.

EXAMPLES IN THE PRACTICE OF MEASUREMENT.

1. Coincidence of terminal boundaries of length with graduation marks of scale or rule to be verified.

2. Coincidence of surface of liquid with a line on a graduated vessel denotes a volume equal to that bounded by the vessel and the plane passing through the mark in question.

3. Similar effects on the two arms of a balance, or on a spring, are judged by the coincidence of a pointer with a mark on a graduated scale.

4. Equal times are judged by similar movements of the same

pendulum over a given mark, or by the movement of a pointer over equal distances on a clock face.

5. Bodies are in the same thermal state, when they bring the free surface of the mercury in a thermometer level with the same mark on the scale.

6. Bodies are in the same electric condition, when they bring the pointer of a voltmeter against the same mark.

EXERCISES.

1. Find the length of a centimetre in decimal parts of an inch, by ascertaining the value of 10 centimetres and dividing by 10.

Check your result by that obtained, when 50 or 60 centimetres are measured against a yard-scale.

Ascertain, as closely as possible, the number of millimetres in an inch, and note the greater accuracy obtainable, when the number of millimetres in 10 inches is observed.

2. Measure the circumference of a cylindrical body, by finding the length of a piece of thread which will just encircle it. Then extend the process, and increase the accuracy of your result, by winding the thread, which must be prevented from overlapping, several times round the cylinder, dividing the total length of the thread by the total number of coils wrapped.

This method is equivalent to repeating the operation of measurement several times, and calculating the mean value.

3. Ascertain the diameter of a cylinder or coin by means of the calipers, or by placing it between two rectangular blocks placed upright on a scale. Repeat the experiment on a sphere with the aid of rough calipers, made by fitting sliding brass pointers with straight edges to a common rule.

Carry out, and compare with the last experiment, the method of finding the circumference of a coin, by marking it with a spot of ink, rolling the coin over paper, and then measuring the distance between the two ink-marks.

4. By transferring the extremities of a given length along parallel lines to a convenient position, find the distance between two points which cannot be directly measured.

Select a rectangular block of wood, mark a point on its upper and also on its lower surface, and ascertain the distance between them, by means of lines drawn parallel to the straight edges of the block and prolonged upon a piece of paper placed under the block. The marks are not to be in a vertical line, but far enough away from the perpendicular to require the exercise of some thought in overcoming the difficulty. It will then be noticed that two pairs of parallel lines are needed, and that the thickness of the block must be taken into account. For this purpose the block may be moved, and

the measurement taken from one point on the paper to an upper edge of the block standing directly over the other point determined.

5. You are given three vessels, holding 3, 4, and 7 cubic centimetres respectively. Proceed to measure out 5 cubic centimetres and also 9 cubic centimetres of a liquid.

How could you prepare a mass weighing 7 units, by using only bodies of weights 11, 15, and 17 units?

6. Carefully weigh an empty beaker, then, again, when 20 or 30 cubic centimetres of water have been run into it from a burette. From the increase in weight calculate the value of a single cubic centimetre of water.

Then, on the necessary assumption that each cubic centimetre of water has the same mass, ascertain the *volume* of a given quantity of water by finding its *weight*. (Check your result by afterwards measuring the water in a graduated vessel.)

As a further exercise, make accurate estimations of the weights of unit volumes of other liquids.

7. The volume of a body can be estimated by the quantity of water it will displace, in several ways:—

- (1) By means of the graduated burette.—The change of level of the water, when the body is immersed in it, directly shows the required volume.
- (2) By using a glass tube without graduation marks.—It should be fitted with an indiarubber tube and a clip for delivery. Partly fill with water and mark in some way its level (by thread or a mark on gummed paper). Now introduce the given body, and allow the water to run into a graduated vessel until the original level is reached. As in the preceding method, the excess of water measures the volume of the given body.
- (3) By use of the balance.—Weigh the body suspended from one arm of a balance first in the air, and then weigh it when dipping in a beaker of water and partially supported by the water. The difference of the two values represents the mass of water displaced, and, as has been already shown, the volume may be learnt from the mass.
- (4) By using Nicholson's hydrometer.—This process is analogous to the last. Place the body in the top pan, and add weights, until the hydrometer sinks in the water up to a certain mark. Then place the body in the lower pan, and remove weights, until the same equilibrium is established. The weights taken off represent the mass of water displaced, or, in other words, the volume of the given body indirectly.
- (5) By using a Jolly's balance.—The method is similar to that of the preceding experiment, the only difference being that the volume of the water displaced is gauged by the extension of a spring.

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For rough experiments, a length of thin elastic may replace the delicate spring employed in a good instrument.

8. Measure the capacity of equal lengths of glass tubing, of burette tubing, and of a narrow beaker, by ascertaining the length of column given by equal volumes of water in each. The capacities of equal lengths are easily calculable from these results.

Calculate the surface area in each case.

Notice, that with a smaller surface there is a greater chance of accuracy in your results.

9. Compare the distances between the calibration-marks of a good thermometer, with the graduation-marks of a good scale. Inasmuch as equal increments of volume are supposed to be shown by the marks on the thermometer, the distances between them should not be equal, unless the bore is even.

10. Take a moderately wide tube or vessel of even bore, and by measuring the changes of level produced, when two or more bodies are dropped separately into water contained therein, ascertain the relative volumes of the bodies.

Compare your results with those obtained by using the balance. Write out a list of the possible errors in each method.

11. Knowing that πr^2 = area of a circle, and that sectional area $\times$ height = volume for a cylinder, calculate the diameter of a circular tube of even bore, 40 centimetres of which holds 210 cubic centimetres.

Calculate in a similar manner, the diameter of a graduated vessel, checking your results by actual measurement. ($\pi = 3.14$ about, and stands for the ratio of the circumference to the diameter, *i.e.* $\frac{\text{length of circ.}}{\text{length of diam.}} = 3.14$.)

12. Measure the surface of a table and calculate (*a*) the volume of a cube, and (*b*) the diameter of a sphere which will have the same total surface. A cube has six faces of equal area, and the surface of a sphere is calculated from $4\pi r^2$.

13. By means of a magnet find the cardinal points, and ascertain the exact direction in which a bench lies. Draw a plan to scale showing its position with regard to these points.

14. With the help of an atlas, find the direction of London, San Francisco, and the North Pole with regard to the bench.

The "declination" of the magnet diminishes in England at the rate of about 7' yearly. When will it point to true North? It is now (1898) 16° 29' at Greenwich.

15. Measure the height of a body from the ground, and by looking along a straight edge, find its direction in a horizontal plane with regard to two fixed points in the room, which are a known distance apart.

Then remove the object, and from a calculation based on the measurements you have taken, replace it in its original position.

Note that the position of a point on a plane surface may be located by two measurements; to find the position in space, a third measurement, in another plane, not parallel, is necessary.

As another experiment, on the estimation of a position by indirect measurement, estimate the position of the centre of a sphere by measurement of its diameter, and compare the result with that obtained by using a *spherometer*.

16. Find the volume of a solid pyramid, by introducing it into a graduated tube half-filled with water, or by any other of the methods previously mentioned.

Check your result by calculating the volume from the linear dimensions of the body.

Then find the mass of the body in grammes, and divide this number by the number of units of volume. The number thus obtained represents directly the *density* of the body as compared with water. Why is this so?

17. Take some zinc or copper foil. Cut out a piece, the exact area of which is 1 sq. inch. Weigh it, and then calculate what weight of foil would cover the table at which you are working.

Calculate the weight of a square decimetre of the foil.

Find its volume and, from the weight and volume, calculate the density of the metal.

What would be the area of 25 grammes of the same foil?

18. Plot on squared paper the relation between mass and volume, in the case of mercury, iron, copper, and alcohol. Then read off from it the volume of 26.7 grammes of each substance.

Paper ruled in squares of 2 or 5 millimetres is exceedingly useful for recording, in a graphic way, the results of a series of experiments involving two connected quantities.

Suppose that you wish to express graphically the relation between the length and breadth of rectangles of equal area. Assume the distance between the squares in the horizontal and vertical directions to represent respectively 1 centimetre of the length and the breadth of the rectangles. In accordance with this agreement mark off, on two lines at right angles, the two linear dimensions of various rectangles of area 16 sq. centimetres, 4×4 , 5×3.2 , 6×2.6 , 8×2 , 12×1.3 , etc., which you obtain by arithmetical experiments. Make crosses at the appropriate vertical distance over each horizontal mark. It will then be seen that these are not in a straight line, but by bending a thin lath a line can be drawn which will pass through all of them.¹

Suppose that the length of a rectangle of area 16 sq. centimetres and

¹ This curve, known in geometry as a *hyperbola*, has many important properties. With these we are not so much concerned, as with the applications of the *graphical method* of recording observations.

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breadth 2·3 centimetres be required. On the curve previously found, make a mark in line with 2·3 on the vertical scale. It will be found to be almost exactly above the seventh horizontal square, signifying that the required length is about 7 centimetres.

Note that squared paper not only permits a graphic record to be made, but also enables calculations relating to two connected quantities to be rapidly performed.

19. Dissolve 25 gram salt in 150 cubic centimetres of water. How much salt will there be in 30 cubic centimetres of the solution?

Prove that you are correct by carefully evaporating down this amount in an evaporating dish of which you have previously ascertained the exact weight.

20. What method of solution will enable you to obtain 0·0005 gram of a solid?

21. Attach an iron ball, of about 1 lb. weight, to a string of 1 metre length. Count the number of oscillations it makes in a minute. Repeat this three times and take the mean as true number. Shorten the string by 10 centimetres and repeat the experiment. Continue this till you reach 20 centimetres length. Then draw on squared paper a curve, which will show at once the number of oscillations for any given length of string.

Note that in estimating the length of a pendulum, care must be taken to measure exactly from point of suspension to the centre of the ball. What difference would it make if the ball were twice as heavy?

Try to ascertain the relation between the length of the pendulum and the number of beats per second.

22. Make a water clock, another kind of instrument for recording intervals of time, which you may compare with your pendulum. It may be conveniently done by using a burette, and carefully regulating the tap-opening to allow the escape of a known quantity of water per second. It may be checked by a metronome beating seconds. Ascertain, if possible, whether the rate of flow is constant, or whether it is more rapid when the column of water in the burette is longer.

23. Draw a circle, and in it place the hour-figures of a clock in their correct positions. Outside this draw a second circle, and mark off on it the points of the compass and degrees. You will now be able to find the number of degrees which correspond to intervals of time on the clock. Make use of this to ascertain the value of the angles which the hands of a clock make at various hours.

24. Construct a paper vernier to read accurately with an inch-scale to $\frac{1}{32}$ th of an inch.

25. Construct in three ways a scale with vernier, reading to $\frac{1}{32}$ in., and in the two ways a scale and vernier reading to 0·2 of a millimetre.

26. Describe by the aid of a diagram some form of screw-gauge which will read to $\frac{1}{100}$ th of a millimetre. What linear distance corresponds to

73 divisions on the head of a screw-gauge, the pitch of which is $\frac{1}{2}$ millimetre, and the number of divisions on the head, 120?

27. Draw a square with a side of 24 centimetres; divide it up into square inches; find out how many square centimetres in each inch, and then write down the total area in square inches and the fraction of a square inch.

28. Draw on squared paper an irregular rectilineal figure, then divide it up into triangles, and ascertain the total area by calculating the area of each triangle. Correct your calculations by counting the number of squares contained in it.

29. Draw on squared paper a square, a triangle, a circle, a parallelogram, and an ellipse, all to be (as nearly as possible) of equal area. Cut out in cardboard figures of this size and weigh each. What result do you obtain?

30. Given 100 cubic centimetres of solution of density 1.5; how much water must be added to bring density down to 1.1?

31. By making use of a table of densities, find the volume of a kilogramme of mercury, lead, ice, and brass; also calculate the weight of a cubic decimetre of each.

32. A locomotive driving-wheel has a diameter of 7 ft.; how many revolutions does it make in 10 miles? The wheel of a cycle makes 660 revolutions in a mile; what is its diameter?

33. Measure the pitch of several ordinary screws. Show how many turns in each case will drive the screw 2 in. into a piece of wood. Test your results by actually turning the screws to that depth through a piece of cardboard.

34. Make a rough wheel-measurer, by fixing a wheel with a graduated rim on a screwed axle, so that as the wheel rotates it goes forward along the screw. Utilise this instrument for measuring the outlines of various regular and irregular figures, also the distances between various objects on the table.¹

35. Prove experimentally (by measurements and by immersion in water) that the volume of a cone is $\frac{1}{3}$ volume of a cylinder of same height and base; also that the volume of a sphere is equal to $\frac{2}{3}$ volume of a cylinder circumscribing the sphere. Wooden models for this purpose are easily procured.

36. The following exercises are of importance in that they accustom the student to compare, by repeated experiment, the relations existing between linear, superficial, and cubical measure, at the same time enabling him to contrast the English and metric systems of measurement. Models of suitable sizes and of any material are easily procured.

You are provided with a **Cube**.

Measure one side of it in millimetres: from this calculate its total

¹ A simple and serviceable modification of this instrument may be made by fixing a circular piece of cardboard on a screw.

amount of surface in square centimetres, and draw a figure of this size on squared paper to check your calculation.

Calculate what the surface would be in square inches and a fraction of a square inch, and prove that you are right, by measuring the cube again with a foot-rule.

Calculate its volume, and correct your answer by immersing it in water in a graduated vessel.

Weigh the cube, and calculate from this the weight of 1 cubic centimetre of the substance of which it is composed. Compare your answer with the known density.

If the cube were cut up into thin sheets, 1 millimetre each in thickness, what surface would it cover?

What would be the diameter of a sphere equal in volume to the cube?

You are given a **Sphere**.

Find the circumference of the sphere, and from this calculate its diameter.

Find the diameter, and from this calculate the circumference, and compare the results with answers to questions above.

Find the area of the sphere roughly in square centimetres, by fitting paper over a quadrant, and draw a figure of this area on squared paper.

What is the area of a circle with diameter equal to that of the sphere?

Using the formula $\frac{4}{3}\pi r^3$, find the volume of the sphere, and prove that you are correct by finding the amount of water it displaces.

Knowing the density of the substance of which the sphere is made, calculate its weight and test your calculation by weighing.

The above experiments may well be repeated with English measures, which can be reduced to metric values and compared with the results already obtained.

It is advisable to continue experiments on similar lines with a **Prism**, a **Pyramid**, a **Cylinder**, and a **Cone**, in order that the various ways of calculating areas and volumes may be thoroughly mastered.

37. If the time taken by the earth to rotate through 360° be known as 24 hours, what will be the time at Winnipeg (about 100° W. long. of Greenwich) when it is 1 hr. 20 min. p.m. at Singapore (100° E. long.)?

What will be the difference of time between the true North Pole and the magnetic North Pole, which is situated (1897) in $96^\circ 41'$ W. long.?

38. The longitude of any place is ascertained by comparing the time there with true Greenwich time; the latitude is found out by taking the altitude of the Pole Star, which (in the Northern Hemisphere) measures directly the distance in degrees from the equator, or from calculations based upon the altitude of the sun at noon.

State what instruments you would require in order to find the position of a ship at sea.

Remember a good chronometer goes on continuously marking equal intervals of time, while the highest point of the sun, as seen from a ship,

will be reached at a *time of day* which depends on the position of the ship upon the earth's surface. In other words, though the standard for measuring time (the change by which all other changes are measured) is the uniform rotation of the earth, and the same fractions of that standard interval must be the same everywhere, yet the moment or incident called *noon* is wholly a matter of *position on the earth's surface*.

Demonstration of these points with the aid of models is strongly recommended.

CHAPTER III

THE MEASUREMENT OF COMPOUND QUANTITIES

Bodies each possess more than one quality, and more than one quantity, likewise, can be exhibited by the same body, and measured with respect to it.

There is no need to point out the existence of several properties in any given object. Colour, hardness, texture are among the several coexisting qualities by which we recognise a body, and through which impressions of the body reach us in a group. These are the things which make up the identity of an object.

In a precisely similar manner, impressions which are measurable may be jointly received from the same body, and illustrations are about to be given. It may be stated here, that both qualities and quantities reach us *through our senses*, without the aid of which no knowledge of the outer world could be gained. Or, it may be said, that qualities and quantities are alike in being impressions made upon us, through the *mediation* of the sense-organs.

Quantity, strictly speaking, is the "how much" of a quality, though a quality which can be measured is often spoken of as quantity, instead of using the longer term *a quantity of a quality*. Some qualities are not measurable, but this is due to our knowledge of them being incomplete.

It is important to give as much time as possible to trying to understand what the word **quantity** means, for the word will have to be used, again and again, in learning Natural Science. In fact, a right understanding of the meaning of quantity is the foundation of all accurate knowledge. And when the significance

of quantity and its measurement are understood, the next step to be taken is to learn, that there are *different kinds of quantities*, and that some are simple while others are complex. We have had some exercise in the measurement of quantities which are simple, for example, *length*, *mass*, and *time*. We proceed now to deal with compound quantities, and we find, that quantities of this kind are *made up of simple ones*.

These simpler quantities may be combined together in various ways to produce values which are of great importance. For instance, **density** is a value derived in a certain way from quantities of mass and volume. **Speed**, again, is a compound quantity derived from length and time.

These statements are not perfectly correct, but they must stand for the present. Any kind of appearance or fact may be looked at from different sides, sometimes from many sides. So, too, the facts which we are attempting to measure have their diverse aspects.

Density.—Weigh equal volumes of water, alcohol, glycerine, and benzene in a graduated vessel, and note the variation in the weights.

Whether this result is due to different states of aggregation or condensation of the liquids, the particles of glycerine, for example, being considered more closely packed together than those of water,¹ and the latter than the particles of spirit, or whether it is due to the particles themselves being heavier or lighter, we have no means at present of deciding.

Solids, too, exhibit in a striking degree this variation in density. Wood and paraffin are appreciably lighter than water, and float upon it, while glass, iron, brass, and lead are very much heavier, and sink immediately when placed in it.

Cut some wood, paraffin, and lead to convenient shapes, enabling their volumes to be roughly calculated. Weigh the bodies on a balance. Also measure their volumes more accurately, by noticing the quantity of water they will displace in a graduated vessel.

¹ It is noteworthy that the densities of many metals are increased by hammering, that is to say, their particles become more closely packed together.

The densities of bodies may be defined as *the ratios which represent the relative quantities of matter in equal volumes*. The density of a body may, therefore, be found *by dividing the numerical value of the weight by that of the volume*.

If we compare the quantity of matter in a given body with its own volume of water at 4° C. we obtain a value called its specific gravity. Inasmuch as the density of water is taken as unity (1 cubic centimetre contains 1 gram), the same ratios represent densities and specific gravities in the metric system.

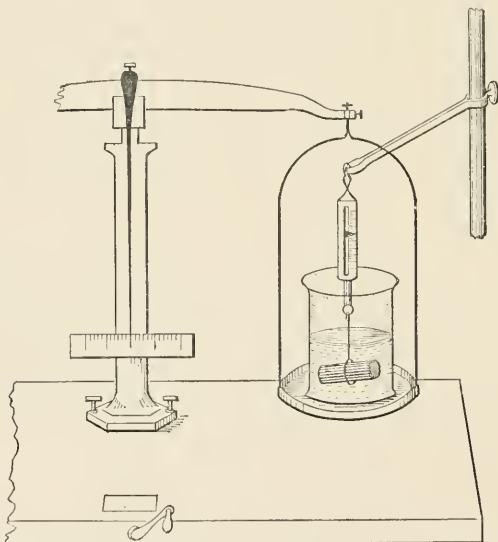


FIG. 1.—Apparatus arranged for showing loss of weight of a body suspended in water.

It will be noted that density and specific gravity are alike in being expressed by *numbers*, but they are numbers which represent a relation or *ratio* between two other numbers.

It is not difficult to understand that a liquid, water, for example, may act as a partial support, and, for that reason, a body immersed in a liquid would not be so forcibly pulled

towards the earth. This is made more evident by the following experiment:—

Balance a beaker of water in one pan of a balance (Fig. 1). Then immerse in it a body attached to a delicate spring-balance, supported from a retort-stand. Add weights to the weight-pan to restore equilibrium, and note that they exactly equal the apparent diminution of weight in the body, as shown by the spring-balance. What the suspended body loses, as shown by the spring, is felt by the supporting liquid, and indicated on the balance. *There is nothing really lost.*

In using **Nicholson's Hydrometer**, or **Jolly's Balance**, it is clear, that the difference perceived in the weight *has something to do with the volume of the water displaced*. The downward pull on the hydrometer, caused by the weight of the body, is the same whether the body be in the upper or lower pan, but in the latter position the body *displaces* a volume of water equal to its own volume. This portion may be supposed to rise to the top, and surround the upper part of the instrument, making it appear lower in the water (see Fig. 2). To place the hydrometer in the same position as before, with regard to the level of the water, weights, equal to the *mass of the displaced water*, must be removed from the upper pan. The hydrometer then rises through a certain distance, to compensate for the disturbance in the disposition of the water. And if we know the mass of the water displaced, we know its volume, and, therefore, the volume also of the body which displaces it.

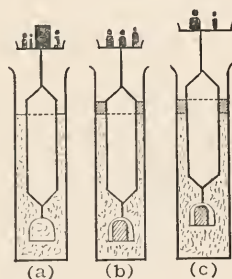


FIG. 2.—The Hydrometer.

a, With body in the upper pan. *b*, With body in the lower pan. *c*, With weights removed from the upper pan in order to place the instrument in the same position with regard to the level of the water as in *a*.

In *b* and *c* the displaced water is indicated by shading.

Position.—In position we have another illustration of a complex value. *Two operations of measurement at least* are needed, to enable us to denote any given position. It will be admitted that position cannot be described, unless there be some

fixed point of reference. Direction, too, is meaningless, except it be described in connection with some known starting-point. The words *right* and *left*, *top* and *bottom*, convey no information, unless they are used with reference to something which is known and fixed.

Now, in order to give information about any position, three items of knowledge are requisite. Firstly, the **plane** must be known; secondly, the **direction** in that plane; and, thirdly, the **distance** in that direction. These things at least must always be part of our knowledge, a direction and a distance in a known plane. In most of our everyday requirements, the plane is always the same, namely, that of the earth's surface. And then, even when we are dealing with the surface of the earth, and assuming it to be a plane, no description or information about position can be based upon less than *two values* obtained by measurement. Two distances, or an angle and a distance combined, taken from fixed points or lines, must be known.

A familiar instance of description of position, and one affording an illustration of the simplest method, is seen in the use of **latitude** and **longitude** in geography.

The words north, south, east, and west indicate to us clearly enough the method adopted for defining position on the earth's surface. It is an adaptation of the simplest process which can serve for that definition, that in which two lines at right angles are used. The meaning of these words, north, south, etc., with regard to two such lines is well known. But in reality they refer not merely to points, but to *directions*. A determination of the direction in which the real north lies will enable the right names to be given to the other directions.

A system of lines intersecting at right angles enables us to define position on a given surface, but in the case of the earth something more is needed, for our names of direction have, at present, nothing fixed but their relation to one another. They may be changed as a whole, and are fixed only with regard to the paper on which they are drawn. But some fixed point is essential in defining real position.

A definite object in London might be taken as the point of

reference. But there happens to be a point of reference which is independent of human location and of national history. It is based upon a great fact of nature, **the rotation of the earth**. One end of the imaginary **axis** upon which the earth rotates is called the north, and the other end the south. These points are the real North and South Poles, and *all paths on the earth leading to them* are said to point **North** and **South** respectively.

It is clear that points which depend upon the rotation of the earth are readily referred to, assuming the manner of rotation to remain constant. The alternation of day and night, as a result of periodic exposure of a given surface to the sun, furnishes one source of information. In our own latitudes, the sun at its highest point is in the south. South of the tropics, the sun at its highest is in the north. At the equator, it is overhead. Again, the Pole Star at night tells us the north, the axis of the earth always pointing towards it, and, in consequence, the other stars and constellations apparently circle round the Pole Star.

The **Mariner's Compass**, that is, a magnet so balanced or suspended that it moves freely, will always point in the same direction, if no iron or other magnet be near it, and this direction is towards the **North Magnetic Pole** (that is, it will lie in the plane including the two magnetic poles). Now the position of this pole, with regard to the real north, is known accurately, and though it varies year by year, its rate of variation is known. If the magnet were our sole guide, it would not be an accurate one, but the real north being fixed, the magnet, with its known *declination*, is a convenient and ready guide on occasions when elaborate observations could not be carried out.

When we consider the surface of the earth, it will be found that two difficulties exist in practical measurement, which are not presented by a small plane surface. The surface of the earth is spherical, and the distances involved are very great. Measurement from two lines alone would lead to numerical values inconveniently great.

Now the first difficulty may be removed by using, as our lines of reference, two *circles* lying at right angles to one another. One of these circles, that lying in a plane passing through north

and south is the **meridian**, that lying east and west is the **equator**.

The second difficulty is obviated by using *a series of circles* passing north and south, instead of one alone. These circles are all equidistant at the equator, and they all intersect at the North and South Poles. These, symmetrically arranged, are depicted on an atlas of the globe, and are spoken of as lines of **longitude** or meridians. They are numbered east and west, starting from the meridian of **Greenwich**.

Adopting a similar plan, and starting from the equator, we have a number of equidistant parallels of **latitude**, always cutting the lines of longitude at right angles. Finally, we may say, that the fixed points essential to geographical measurement are the North and South Poles, which are fixed by the manner of the earth's rotation, and every position on the earth's surface must be described by referring to these points directly or indirectly.

Graphic Methods of Recording Quantities.—In just the same fashion as locality is defined, by its distance from two known lines at right angles to one another, so may a value, which is made up of two other quantities, be recorded by distances, drawn to scale, from two lines at right angles. And there is no method of record more convenient than this. Each of the component quantities is recorded by its own distance, the relation of the distance to the quantity being regulated in accordance with a scale agreed upon. For example, each millimetre of length may represent a unit of the component quantity or, it may be, an inch of length may be selected for the purpose. But the scale once determined, *the position of a given point on such a plan stands as a record of two values, and it represents at a glance the composition of the quantity in question.* Moreover, two or more such points, of which the position has been calculated, may be recorded on the same plan, and it is clear, that in such case a direct and simple mode of comparison between them becomes possible. And, in addition, any *variation* in the factors, which jointly constitute the quantity, may be made evident.

By a prosecution of this mode of recording observation, a

valuable aid to research is obtained from the use of lines, or, as they are frequently called, *curves*, which express in a direct manner the **variation of a given quantity**, or of a given state, in accordance with a known change of conditions. Upon certain changes in the conditions or circumstances of a body, certain of its properties may undergo change.

It may be desirable to learn the exact manner in which one quantity varies with another *connected* quantity. The **law** of that connection, in fact, may be under investigation. A diagram, based upon a scheme of measurement of this nature, affords the best and the quickest means of conveying the results of that research. It constitutes what is called a **graphic record**. The curve exhibited expresses the constant relation between the quantities under observation. Time and space are economised, by using a series of positions on a diagram in the place of tables of numbers. Illustrations of graphic records will be given hereafter as opportunity offers.

Speed.—There may not appear to be any resemblance between the two values known as speed and position, yet a resemblance can be found in the fact that they are both made up of *two distinct magnitudes*. Density is a number or ratio, which can only be obtained after making a measurement both of the total **mass** and the total **volume** of a body, and speed is likewise a number or ratio, which cannot be fixed upon till two values have been ascertained, first, the **distance** through which a body has moved, and, second, the **time** occupied in the motion.

If a speed be *uniform*, these quantities may be measured over any portion of the path traversed by the body, or at any stage in its progress. But if a body move irregularly, it is necessary to ascertain the distances passed over in a large number of small intervals of time, in order to gain accurate information as to the speed. Either an *average rate* of displacement is derived from an average of the values so obtained, or separate statements must be made concerning the magnitudes at various points of time. And a statement of this kind can only be approximately true, for the speed which is quoted for a given

interval assumes that the value does not change during that time, or at least maintains an average of that value. But as a matter of fact the speed at a given point of time may be a very transitory state. It may last only for a very small fraction of time.

Illustrations of other Quantities.—The question *how much* may be put to many things. Indeed it is difficult to mention things to which it does not apply, and there is little work in Physics which is not made up almost wholly of measuring quantities of some kind or other. Part of the work, however, consists in *distinguishing* various kinds of quantity from one another, and this precedes measurement.

One such quantity is **Heat**. Another is **Electricity**. Both these phenomena are very difficult to understand, though they are easy to measure. It is easy to compare one quantity of heat with another, and it is easy enough to measure electricity, although we may remain ignorant of what constitutes heat in the one case, and electricity in the other.

Yet in order to gain a little insight into the subjects which are treated in Physics, and these are, in the main, heat, electricity, and light, it is advisable to be content for the present with description and statement, rather than attempt to make a distinct image of the things themselves. The **real facts**, for which these names stand as symbols, are very difficult to understand, although we may be familiar with some of the features which they present to us, and in spite of the truth, that much may be learnt, and learnt accurately, about the effects of these things. Indeed, it is important to grasp as early as possible the main lines upon which physical research is conducted, and for that reason we repeat, that the measurement of these things as **quantities** is the chief work of Physics. They are to be recognised, and dealt with, as quantities, *long before it is possible to understand their real nature*.

To measure heat, it is necessary to have a standard quantity. And the same condition holds with any physical measurement. If a quantity of water be halved, then the two equal parts contain equal quantities of heat. If these two equal quantities of

the same kind of matter be now changed equally with regard to their thermal state, we may describe the event as due to *equal quantities of heat* being added to them. If the equal quantities of water be placed in contact with the same sources of heat, they will each receive or lose, roughly speaking, equal quantities of heat in the same time.

When equal quantities of the same matter contain equal quantities of heat, they impress us similarly as regards the sensation of **temperature**. When they receive equal quantities of heat, they are similarly changed as regards that same sensation.

And this **sensation** is the sole *direct* means of obtaining information about what is known as heat. Indirect means there are in numbers, and it is fortunate for our knowledge of heat that they exist, for our sensations are well known to be untrustworthy, and that of temperature in particular.

A familiar illustration of this untrustworthiness of the sense of temperature occurs when the hand is placed successively in hot and tepid water. The tepid water in that case impresses us as cold, whereas it appears warm when the hand is first dipped in water which is quite cold. The direct impression gained through the sensory nerves depends very much upon the impression with which it is compared. The previous circumstances greatly determine the results which are to follow; and this renders the information useless for scientific purposes.

But there is an instrument called the **thermometer**, to be more fully described later, upon which impressions are made, and we may safely take them as correct indications of temperature. It may be noted here, that the quantity we are dealing with is *heat*, but all that we are learning about it is gained from states of *temperature*.

Change of Density usually shows Change of Temperature.—As the temperature of a body changes, or, as it may be described, when the quantity of heat in a body changes, it usually varies in volume. The quantity of matter always remains unaltered, but the size of the body may vary. This constitutes an alteration in density. A change in size is *not an invariable effect* of a thermal change, but it is mentioned, because

it is the effect upon which all practical measurement of the quantity known as heat is based. The use of the thermometer is founded upon this fact, and without the thermometer a prompt and direct measurement of heat would not be possible.

Weigh a piece of ice in a beaker. Allow the ice to melt and weigh again. Its mass is unaltered. Any number of similar experiments may be performed, with the result that matter will be found invariable in quantity whether hot or cold.

Any apparent exceptions to this statement will be due to some partial change of state, and the consequent inability to weigh the matter in its entirety. If a liquid partly evaporates, or a solid partly sublimates, when heated, the portion which may escape from the vessel being used, frequently escapes our observation. By the use of a closed vessel all parts of the body would be retained, and a change of temperature would be found inoperative with regard to quantity of matter. And the same may be said of **every change of which we have knowledge**, as well as of change of temperature.

But size does change as a rule—in some cases only slightly, in others more rapidly.

Fill a small flask up to the neck with water, mark the level, and place it in contact with a hotter body, for example, a gas flame. The level will change. An increase in volume is evident, yet both the vessel and its contents grow larger, and this is so prominent in the case of the water that it outsteps the expansion of the vessel. The change of level represents the expansion of the water *in excess of that of the vessel containing it*.

Fit a glass tube of narrow bore in the neck of a flask by means of a cork. Take care that the fitting is close. When this is done, fill the flask with some coloured solution (potassium permanganate, for example), insert the cork and tube, so that the coloured liquid appears in the tube. The change of level due to a change of temperature is now exaggerated and made plainer.

A modification of this arrangement provides a thermometer. This instrument consists of a reservoir of mercury, which runs over into a thin thread of the liquid within a stem. A small change of temperature is promptly marked by a change in the length of this capillary overflow. In the process of constructing the instrument, air is excluded, so that there is nothing to resist an increase in the volume of the mercury.

An instrument of this kind without any connection with scales of graduation would be of use in informing us when temperatures are alike and when they differ. Placed in contact with two bodies in turn, it would indicate by its level whether they are in the *same thermal state* or not. But more than this it cannot yet tell us.

The measurement of quantity of heat requires other things to be observed and considered. The facts upon which the **graduation** of the thermometer is based require first to be discussed at greater length, as is done in the next chapter. But at present we must be content to realise that there are other quantities than those already mentioned to be measured, and that their measurement may be carried out by paying attention to certain changes which come under our observation. The measurement of quantity of *heat* is based, in fact, upon another measurement, that of *volume*. Heat is never directly measured. Our information about it *is always obtained indirectly*. From simple observations we pass to those which are more complex, and the more exact our knowledge of simple facts and elementary measurements, the better equipped are we for more advanced work.

The thermometer enables us to tell with great accuracy when the temperature of the two bodies is the same. The same indications on that instrument are certain to be due to the similar causes. It is the *similarity of state with regard to temperature* which brings the level of the mercury to the same point. But more than this cannot be stated with any truth.

Again, it is important to recognise that the same temperature, as marked by the thermometer, gives us very little information as regards the quantity of heat. *The thermometer itself tells us only of thermal states, i.e., of temperature.* But the quantity of **heat** contained in the body will depend upon the quantity of **matter**. Or, taking another view, we may say that the **quantity of heat** needed to bring about the same change of temperature in two bodies *will depend upon their relative masses*. It takes a large quantity of water longer in coming to the boiling-point than a small one, and it is evident on all occasions that the quantity of matter, which is changed, must be taken into account in all thermal events.

More than this may be said. The **kind** of matter as well as the **quantity** affects the results. The same change of temperature in equal quantities of different substances is not at all the same thing. The more rapid changes of temperature, whether of rising or falling, apparent in metals as compared with other bodies, give an indication of this fact.

Though temperature, as a state of matter, does not impress us as a quantity, and it is difficult to understand how it can be measured, *the connection with matter, or the combination of the two things, a state and a mass*, gives us at once the important reality, **a quantity of heat**, and upon the accurate measurement of this complex quantity much depends.

The balance enables us to decide when two quantities of matter are equal, and, by using the thermometer, we are able to perceive when two bodies are at the same temperature. It is advisable to consider these two operations together, and to satisfy oneself that they are similar exercises of the judgment. At the same time it must not be forgotten, that though the grounds for decision are alike in each case, there is a fundamental difference between the two kinds of equality.

Two quantities of matter which produce the same effect, and are therefore equal, can be added together, and made to produce double the effect of one, a fact upon which the comparison of different quantities of matter is based. But there is no such addition of similar states of temperature possible, unless other things are also taken into account.

There is nothing gained by adding temperature values together, irrespective of other circumstances. We cannot say that one temperature is double or treble another, as we can in speaking of masses. As a matter of fact, temperature is a *rate* rather than a *quantity*.

EXERCISES AND QUESTIONS.

1. Find the density of the glass in a glass stopper in six different ways, by using—

- (1) a balance and a graduated tube,
- (2) a balance and an ungraduated burette,
- (3) the balance alone,
- (4) the hydrometer,
- (5) Jolly's balance,
- (6) arithmetical calculations and a balance.

Make your results as accurate as possible, by taking the mean of two or three observations in each case, and finally compare them with the real specific gravity, as found by careful observers and recorded in tables.

2. The atmospheric pressure will usually support a column of mercury (density 13.6) 76 centimetres high. How high will be the column of glycerine of density 1.26 it can support?

3. Take two tubes connected at the top by indiarubber tubing with a T-shaped tube and draw up columns of two different liquids from separate vessels. The columns may be retained in position by employing a third piece of rubber tubing and a clip. Their densities will be inversely as the true heights of the columns.

Compare the densities of the two liquids by means of the balance, weighing equal volumes of each liquid.

4. You are given the specific gravities of paraffin and of lead. Make observations and calculations in order to ascertain the quantity of the metal embedded in a given piece of wax.

5. Instead of using the spherometer in the ordinary way, make use of it to measure the length of a line. This is done by rolling the wheel along the line, and as the diameter of the wheel and the pitch of the axle-screw are easily ascertained, any number of different measurements may be taken.

6. Find the volume of a cube which shall have a surface equal to that of the bench top. If the material of the cube have a density of 11, what will it weigh?

7. How is it that the same numerical value expresses both the loss of weight, apparent when a body is weighed in water, and the volume of the body, provided the density of water be taken as 1?

8. Find the diameter of a piece of fine tubing (*e.g.* thermometer tubing) by inserting some mercury, measuring the length of the column and weighing the mercury when removed. Calculate from the known density of mercury and the dimensions of a circular cylinder.

9. Measure the ratio of the metre to the yard by using inch and centimetre screw-gauges, and also by the spherometer. Take any given distance, such as the thickness of a disc, by each kind of instrument, and calculate from the results the required ratio.

10. Compare accurately the colour, hardness (scratch with knife), texture, and mass of equal sized pieces of copper, aluminium, wood, glass, steel, lead, etc., and draw up a table in which the comparisons may be read off at once. (Suitable blocks are made for this purpose, and can be easily obtained from any well-known firm.)

11. Explain clearly what you understand by the terms "simple quantity," "compound quantity," and illustrate your answer by giving several examples of each.

12. In order to describe exactly the position of any object in space, what items of knowledge are requisite?

Mark a spot on the bench at which you are working, and then accurately define its position in the room.

13. Find the magnetic N. by using a small compass, and draw a plan of

the room you are working in, indicating its correct position with regard to the points of the compass.

14. Draw in your book an irregular figure with many sides, each of which is a straight line. Assuming the top of the page to be N., describe exactly the direction in which each side of the figure lies.

15. Explain as well as you are able the difference between "quantity of heat" and "temperature."

How is it that a test-tube of boiling-water, which is apparently very hot to the touch, yet contains a smaller quantity of heat than a tank full of water apparently cold to the touch.

16. Conduct a series of experiments to show that the density of water varies with its temperature. Commence with ice-cold water and take the density for every 4° difference up to about 30° or 40° C. Explain the reason of any change you observe.

Momentum.—The quantity of matter, or the mass, of a body is a value which is easily ascertained. The speed with which a body is moving, however, is not as a rule so easily determined as mass—partly because it is a complex quantity, the value of which is dependent upon the measurement of two other quantities, themselves more elementary, namely, time and length; and, for another reason, because time, which is one of the component quantities in speed, does not always admit of very accurate measurement. An event of which time forms part is often difficult to delimit and measure. *Speed* is the rate at which a body moves along its path. *Velocity* is the rate of displacement, and denotes both magnitude and direction.

Momentum is the name given to a quantity which is still more complex than those already described, for it is obtained by taking a quantity, velocity, together with the quantity of matter undergoing motion, into our consideration. And as momentum is a quantity into which both velocity and mass enter, a quantity, in fact, made up of two others, then the *numerical value of momentum* on any occasion is obtained, by multiplying the numerical value of the mass by that of velocity. Why it is necessary and convenient to gain a conception of such a quantity as momentum, will be seen in what follows. The measurement of momentum, when once what is being measured is rightly understood, forms an important step towards a wider knowledge of many occurrences in nature,

The description of the value of momentum, as derived from the product of the number of units of velocity and of mass, gives us an opportunity of regarding that quantity from several points of view. When we realise that—

$$\text{Momentum} = \text{mass} \times \text{velocity},$$

or, to be more accurate, that *the numerical value of momentum is the product of the numerical values of mass and velocity*, it is evident that the following statements are true.

1. The unit of momentum exists, when a unit of mass is moving at the unit velocity.

2. A given quantity of momentum may exist under very different shapes. It may occur when a large quantity of matter moves slowly, or when a small quantity moves rapidly.

3. Matter in motion has a measurable value called momentum, and the same value may be given in an indefinite variety of ways.

Electricity as a Quantity.—An obstacle to the investigation of electricity as a quantity lies in the difficulty of isolating it. It is difficult enough to prevent heat from passing away to neighbouring bodies, but the task is still greater in the case of electricity. A hot body may be touched by another without undergoing any appreciable change, but even momentary contact of certain bodies with one charged with electricity is enough to seriously disturb its electrical state and alter the electrical value.

When certain bodies are rubbed together and then separated, the space between them exhibits a new property. Small bodies in the neighbourhood of either of the rubbed bodies may be shown, by suitable contrivances, to be in a *state of constraint*. This is most readily perceived by their movements. Within the region surrounding the bodies, which are now said to be electrified, the space is in a certain strained condition, and is described as the *electric field*. Sealing-wax, amber, ebonite, and resinous bodies generally, when rubbed with silk, flannel, fur, etc., readily exhibit this phenomenon. By adopting special precautions, most bodies, when rubbed together, may be electrified to some extent.

But electric phenomena may be produced by other methods.

68 MEASUREMENT OF COMPOUND QUANTITIES

Place two strips of copper and zinc in very diluted sulphuric acid. Connect them by means of a wire with any sensitive form of electrometer. A movement indicating constraint, due to electrification, will be observed.

By substituting for the electrometer a coil of wire, within which a magnet is suspended, a far more marked indication of electricity is obtained. A magnet is readily turned by electricity in this state, or, as it is called, a *current* of electricity, and the instrument showing the presence of such a current is called a **galvanometer**. All these effects, whether magnetic or electric, may be measured and compared with one another. There is to be perceived, in all of them, the quality of *more or less*, the sense of *magnitude* or *quantity*.

By observation of the movement of a magnet in the galvanometer, and by consideration of the principles upon which this is constructed, different electric currents may be compared with one another as regards magnitude. Here we come into touch with a new quantity which has to be measured, and *quantity of electricity* may be compared with quantity of heat. They each have their special instrument of measurement, the one the thermometer, the other the galvanometer, but, in each case, the further discussion of their use and construction must be postponed, as a lengthy treatment is necessary.

It would be easy to give a description of many interesting facts about electricity, even at this stage, but disconnected scraps of information do not necessarily add to our comprehension of nature. It is wiser to acquire our information in accordance with a definite and progressive scheme, for then we shall be able to lay hold of a certain number of the more fundamental facts which underlie an endless number of instances. Much of the diversity which is apparent in the multitude of experiments capable of being performed, most of the unexpected things which occur, may, indeed, be reduced by adequate reflection to the operation of a few general principles. Many appearances are presented by a single agent, and differences are often superficial.

Further illustrations of these statements will be afforded, when we come to deal with the phenomena of magnetism. The **polarity** of a magnet, that is, the fact of contrary stresses being

exhibited at the two ends, as exhibited in the mutual action of two magnets—the **direction** in which the magnetic stress acts, as shown by the disposition of iron filings in its neighbourhood—and various other properties of the magnet are easily demonstrated. But if undertaken prematurely, they will be observed unintelligently, whereas it is easy to study them methodically and to learn that *magnetic phenomena are definitely allied with those which are electrical*. And already it has been shown that electricity in motion has a prompt action upon a magnet. The first step to be taken will be to learn how to *measure both electricity and magnetism*, and then to learn the nature of their action on one another.

In the case of **light**, likewise, it is more important to learn something of the reality which is underneath the various optical effects, rather than to deal with the effects at first hand, however attractive that course may appear to be. The attractiveness is soon exhausted and the student is left with little real knowledge.

Moreover, all the various properties which have entered into our discussion *may be exhibited by the same body and at the same time*. For some purposes it may not be necessary to pay attention to more than one of them. The inquiry we have to make may concern one quantity alone. On the other hand, we may need information about two or even more quantities of the kind already described, though the information is not always easy to obtain. In later chapters, too, it will be shown that great attention has to be paid to the rate at which individual quantities change, and also, to the mode in which these changes are related to one another. It may be that one kind of quantity in one body varies, while another change takes place in another body, and sometimes, connected changes take place in the same body. What is important to learn, in either case, is *the manner in which the changes are related*, or, as it is described, what **law** connects them.

For example, it is observable, that momentum may diminish, or disappear altogether, while an increase in temperature occurs. A body moving rapidly, a bullet shot against an iron plate, is stopped suddenly; but in the place of the momentum we have an increase of temperature so great, that the bullet is completely

melted. Now the law connecting these changes is an important one, and it has been accurately determined. Or, again, electricity may disappear from view, while chemical change is effected, or while temperature is increased. The mode or law, in accordance with which these mutual changes occur, is in each case determinable, and forms a great part of our future work.

OBSERVATIONS OF CERTAIN PHYSICAL QUANTITIES.

That heat is a quantity capable of measurement need not be insisted upon again. It is well, however, to consider in what manner it may be measured. We shall find that there are several methods which will serve, and the following exercises are suggested to enforce them.

1. Place small pieces of ice in equal masses of water at the same temperature. Ascertain the quantity of ice afterwards by noting the additional weight. Use large glass beakers. It will be found that there is a lowering of temperature, approximately proportional to the quantity of ice used.

Here, the water loses heat and the ice gains it, and we do not measure *the heat*, but the ice which is changed by the heat. And the result of the observation is to show again, that the quantity of heat is proportional to the quantity of matter in which it produces its effect.

2. Leave in boiling-water, for a few minutes, two equal quantities of copper wire, to which thread has been attached for the purpose of manipulation. Then transfer one to a known quantity of water, and the other to double that quantity, at the same temperature. Note when thermal equilibrium has been reached, that the change of temperature in the smaller quantity of water is double what it is in the larger quantity, or approximately so.

Here, we perceive that equal quantities of heat, or what we may assume for the present purposes to be equal quantities, bring about a change of temperature inversely proportional to the quantity of matter in which it takes place. In other words, the smaller the mass, the greater is the change in the thermal condition corresponding with a given quantity of heat. A product, obtained by multiplying the number of units of mass by the number of degrees of change, measures the quantity of heat for a

given kind of matter. We have no means, at present, for deciding, how this statement is affected when we come to compare different kinds of matter, though we may anticipate observation by saying *that it is affected*.

The product of mass and number of degrees of change in the case of copper does not give the same value as the corresponding product, in the case of the water which is changed by the copper. That quantities of heat are proportional to the change of temperature in each kind of matter is all that can be said.

An important method of measuring quantity of heat lies in the observation of the *quantity of work* it is capable of performing. Unfortunately it is a method which does not lend itself readily to actual demonstration in the laboratory, though almost any piece of machinery in action illustrates the transformation in question. The quantity of work done by any engine in which heat is used will show, that for the same engine the work done is proportional to the heat used. Engines vary in **efficiency**, otherwise it might always be said, that the work performed is a true measure of heat. Of an engine which is ideally efficient, this would be true. A correspondence between heat and work is also apparent in the continuous production of heat, when two bodies are rubbed together. Where there is friction or resistance to the rubbing, heat in proportion to the resistance is brought into existence.

3. Connect a Daniell cell with a large coil of wire, at the centre of which a magnet is suspended so as to move freely, that is, use a galvanometer with a coil large enough to permit only a slight deflection of the magnet. Connect two cells together, and note that the deviation of the magnet is increased. The observation of quantity is here illustrated in another of its forms.

4. Connect two or more Daniell cells (joined in series, *i.e.* zincs and coppers alternating) with any simple form of voltmeter containing very dilute sulphuric acid. A *chemical change* goes on and gas is disengaged. Note the volume of gas liberated in a given time, say six minutes. Next, connect in the same manner four such cells, and note the gas liberated in the same period of time. It will be found about double what it was before.

In this case we measure quantity of current by the amount of chemical change it produces.

5. Observe the rate of oscillations set up in a small magnet, which is free to move about its centre, when it is placed in different situations with regard to a strong bar magnet. The number of oscillations taking place in the same time will be found to vary as the position with regard to the magnet is changed. The strength of what is called the *magnetic field* varies.

The quantity of magnetism, whatever may be the real nature of that agent, is a magnitude, varying according to locality and indicating itself by the rate of movement of an independent magnetic body. The strength of the magnetic field actually varies as the square of the number of oscillations.

6. Allow any small body, of an ounce or more, to fall from varying heights into the pan of a spring compression-balance. Arrange some cotton wool in the pan to break the fall. Ascertain the relation which exists between the distance of the fall and the compression produced in the spring. The act of compression is a performance of work, and that which produces it is the *energy* of the moving body. This kind of energy is distinguished by the term **kinetic energy**. It will be found that the work done is proportional to the distance through which the body falls.

Now it may be accepted as a fact of observation, which requires too much care to be undertaken at the present stage, that the speed, at which a body is moving at the moment it is stopped in its fall to the earth, varies as the *square root of the distance* through which it has fallen. Therefore the work performed under such circumstances is dependent on the square of the speed at which the body is moving, and the kinetic kind of energy varies as the square of the speed. If bodies of varying mass be used, it will be found that the effect produced in compression is proportional to the mass, when the distance of fall is the same.

Hence the quantity known as kinetic energy is estimated from the product of the mass and the square of the speed.¹

¹ Many other exercises of the character described above will suggest themselves to the teacher, as affording illustrations of other modes of measuring complex quantities.

CHAPTER IV

SOME SIMPLE OBSERVATIONS IN WHICH MATTER, TIME, AND SPACE ARE INVOLVED

THE previous chapter has given a clue to the course before us. Our occupation will mainly consist in measuring quantities, and these will become more and more complex as we go on. The things which we undertake to investigate will be found more composite in their nature as we proceed on our course. But before we are able to make a thorough and scientific investigation, it is necessary to extend our observation far enough to include a considerable number of different kinds of facts. Indeed the many changes of nature have to be classified first of all, and after that is carried out they may be inquired into more fully, as is done when we begin to measure them accurately.

The chief instrument in classification, nevertheless, is measurement, though accuracy in measurement may not at first be possible or necessary. And this is a very important principle, needing constant attention, that measurement is not only the end, but even the beginning of all systematic inquiry. Even for ordinary description or recognition some rough sort of measurement or comparison is usually needed.

The quantities which have come before our notice already, *density, speed, momentum, heat, electricity*, etc., may be described as certain **states** of the bodies with which these quantities are associated. We speak, for example, of the kinetic, thermal, or electric state of a body, either when referring exactly to the quantity of motion, heat, or electricity, which may be measured upon it, or when alluding to quantities roughly estimated by some direct comparison with neighbouring bodies. Even in the

latter case some simple process of rapid measurement is carried on by direct observation.

But, for the moment, it is important to recognise that we usually look upon these varying physical quantities as *states or conditions of certain bodies*, though variation in the state of a body is only another phrase for an alteration in a *certain measurable quantity*. Every change in the state of a body, and therefore all the physical and chemical changes which take place in the world, have to be investigated, if they are to form part of our scientific knowledge, by means of the measurement of certain quantities. And this is true even of those preliminary stages of our study which are merely descriptive and classificatory.

Matter in Motion.—A body may exhibit three kinds of movement. It may be undergoing **Translation**, **Rotation**, or **Oscillation**. It may be undergoing more than one of these movements at the same time. The fly-wheel of a stationary engine rotates. In the locomotive it undergoes translation as well as rotation. It may rotate or oscillate while it is being translated. The earth is well known to perform a daily rotation, while it performs its annual movement round the sun, and this annual movement partakes of the character of a rotation and an oscillation. It is an oscillation because it is repeated every year.

Translation is merely displacement. The path followed in the displacement may be straight, curved, or irregular. The observation of displacement necessitates measurements of position, of the kind already described, that is, from at least two fixed points or lines of reference. This being possible, the values, at the beginning and end of the displacement, give the total displacement, though they do not inform us as to the path taken by the body. To ascertain this, either measurements must be made at intermediate points, or its path be followed directly by comparison with some fixed line.

If any part of a body is changed in position while another part remains at rest, or if the parts of a body have not moved along paths, which are parallel to that of the body as a whole, then we have an illustration of **rotation**. Any displacement

in which all the parts of a body do not *equally* share constitutes a rotation. And it is interesting to note that the result of any disturbance in the position of a body may be obtained by a translation combined with a rotation.

In the movement called **oscillation**, the characteristic is *repetition* in some form. The same positions are repeatedly occupied. A given path is traversed again and again. Each point in the path may be alternately passed over from opposite directions, as when a pendulum oscillates, the direction of displacement being periodically reversed; or, in another instance of oscillation, the mode of displacement is such that each position in the path is repeatedly occupied from the same direction. In this case the path traversed by the oscillating body is *circular or elliptical*, whereas it is a *straight line* in the other case.

QUESTIONS AND EXERCISES.

1. How is the position of a body described? Why is it necessary to know more than one distance before position can be explained?
2. How can position be described by means of angles?
3. In the circumference of a circle there are four points similarly situated with regard to two diameters drawn at right angles. How can they be distinguished?
4. How is the locality of a given area defined?
5. Draw a plan of the room to $\frac{1}{8}$ scale (*i.e.* let $\frac{1}{8}$ in. represent 1 ft.), and indicate the points of the compass.
6. What would be the appearance, presented by a body undergoing circular oscillation, when the eyes are placed in the plane of oscillation, *i.e.* when the body is looked at sideways.
7. Compare the appearance presented, when a body moving in a circular path is looked at in the manner indicated in the last question, with the appearance of an ordinary pendulum when looked at from above.
8. Draw a line to represent the path traced by—(1) any point on the outside of a body which spins as it moves on, a spinning-top moving on, for example; and (2) any point on the rim of a wheel rolling along.
9. Draw a diagram to show that in the translation of a rigid body every part of it moves through an equal distance in the same direction.
10. Draw a diagram to show that each part of a rotating body moves with the same angular velocity, that is, every part moves through some arc or other of the same angle, the origin of the angle being the centre of rotation.

Displacement is relative.—When it is said that *displacement is relative*, the word *relative* is used to express the fact that a value or change varies according to the standard by which it is measured, or the starting-point from which it is measured. Now there is no need to dwell upon the fact, that the numerical value of any quantity depends upon the standard adopted. That is well known. But a movement gives an opportunity of drawing attention to another manner in which a magnitude is dependent upon something else, or, as we say, is relative.

If a body is being displaced in a north-easterly direction, a person standing far away in the east would judge it to be moving due north, unless he had some clue to a better judgment. In the absence of other bodies to mark its path, and in case no increase in size became apparent, there would be no indication of anything but a northerly movement.

On the other hand, the body would appear to be moving due east in the sight of a person regarding it from the north. And both these movements do really occur. The body moves east, and it also moves north. But the displacement which appears to take place depends on the point of view. *Motion, then, is relative*, and so are most changes which come under our notice.

As an exercise in the meaning of the term, relative, the following questions may be answered :—

1. Draw a line to show the path of a body falling from the roof of a railway carriage in motion : (a) relative to the carriage ; (b) relative to the earth.

2. Draw lines side by side to show the path of displacement with regard (1) to the train ; (2) to the earth, in the case of a heavy body allowed to fall from the window of a rapidly moving train.

These and other observations of the same kind enforce the proposition that motion is relative, that it depends on the point of reference or point of view.

The distinction between **rest** and **motion** is unreal. A state of rest or motion is relative. It depends upon what we are using for comparison. All observation of displacement assumes the existence of a point at rest, and it is an observation of a change in the relation of two bodies as regards distance. Yet the real state of the body is not taken into account, nor is that necessary.

A book is at rest on a table, yet the table is moving through space at a high speed, and along a path too involved to be understood. The only fact that concerns us is the relation of the book to the table. Its **absolute state** is of no practical importance, even if it could be ascertained.

If the question of motion or rest be rightly understood as a relative matter, it will be easy to grasp the meaning of **acceleration** or change in speed. The change *from rest to motion* is the same as a change in *the rate of motion*. An increase or decrease in speed is a change of the same nature as that which occurs when a body moves from rest. Acceleration is the rate of change of speed, whether it be increasing or decreasing. The essential in acceleration is *change* of speed, whether positive or negative.

The most familiar example of acceleration is that which occurs in the fall of bodies to the earth. A body allowed to fall starts from rest and accelerates, until it is brought to rest by the resistance of another body. It can be proved for any freely falling body, that the *acceleration is constant*, namely, that the rate of change is uniform. Acceleration may occur in any of the classes in which motion has been described to exist. It may take place in translation, rotation, or oscillation. Its meaning, however, will be adequately illustrated by taking the case of translation, and there is no better or more important illustration than that of a body falling to the earth.

THE FALL OF A BODY TO THE EARTH WHEN NOT OBSTRUCTED.

The *rate* at which a body, if not impeded in any way, falls to the earth is the same, whatever be the quantity or kind of matter in the body.

Experimental proof of this statement is readily obtainable. Two bodies, *e.g.*, of wood and iron may be suspended by mechanical or electro-magnetic devices, so that they may be simultaneously released, and the ear will afford proof, that the contacts of the wood and iron with the floor occur at the same instant. Bodies which expose a large surface to the resistance of

the air, in falling, may be found to vary, but this cause of difference will be eliminated if the experiment be conducted in a vacuum, or if one body be enclosed in the other (*e.g.* a piece of paper in a hollow, open, heavy object).

The pendulum affords additional and more easily verified proof of the above proposition. No matter how the quantity or kind of matter of the bob be varied, a pendulum of given length is always attracted to the earth in such a way that its time of swing remains constant.

The Time of Fall.—Within a moderate distance from the earth a body falls through 16 ft. during the first second after it is released, 64 ft. in two seconds, 144 ft. in three seconds, etc. Its rate of movement at the exact instant it is released is zero, but, falling with a constant acceleration, at the end of the first second the *velocity* is 32 ft. per second; at the end of the next second 64 ft. per second; and at the end of t seconds $32t$ ft. per second. The acceleration due to gravity, usually denoted by the letter g , is thus 32 ft. per second per second.¹

It will be noted that the space through which a body travels varies as the square of the time. In two seconds a body traverses four times the space traversed in one second, in three seconds nine times as much, etc.

The student should try to condense the above data, or better still, express his own experimental discoveries in formulæ—connecting s , the space traversed in t seconds, with u its initial velocity, v the final velocity of the body, and g the acceleration of gravity.

Direct demonstrations of the above facts are not easy, owing to the high rate of velocity and the distance from the ground necessary for experiments. Devices for “diluting” or diminishing the effects of gravity, such as **Atwood’s machine**, the smooth **inclined plane**, etc., are therefore resorted to.

In the latter instrument a steel ball, released by an electro-magnetic device, runs down a metal groove (which can be adjusted to any angle of inclination), and establishes an electric connection at the receiving trigger at the bottom of the groove.

¹ More accurately 32.2 ft.

The time between the release and the contact is registered by a water-clock, or other form of chronograph, connected with the electro-magnetic apparatus. For any given inclination of the groove, the *time of transit* will always be as the *square root of the distance* between the triggers.

In Atwood's machine the rate of fall is retarded, by causing a system of two balanced bodies to share in the motion of a third.

Two equal masses are connected by a silk thread, which passes over a pulley turning on friction wheels. A small additional mass is made to rest on the mass near the scale. This causes an acceleration to be given to the whole system, which begins to move slowly, inasmuch as the sole cause of movement is the weight of the small added mass. By trial, the space passed over in one second may be noted, and the movable stage placed there. Then the commencement and end of the fall will agree with two consecutive ticks of a seconds-clock. The space passed over during two seconds will be found to be four times that passed over during one second, and during three seconds the distance will be nine times greater, and so on. In order to give a long drop the pulley should be fixed as high as possible.

By allowing the additional mass to rest, for one second only, on the system, removing it at the expiration of the time by a ring placed in position, the acceleration due to gravity may be calculated. The rate of movement of the balanced masses is observed by placing a stage to receive the falling body at the end of the next second. The acceleration produced will be, to that of gravity, in the ratio of the additional mass to the mass of all three bodies together.

An interesting experiment, to calculate the time taken in the fall of a body, may be carried out by allowing the body to fall upon the base of a pendulum of long period. It is arranged that the falling body shall be placed at such a height that if the pendulum starts swinging when the body begins to fall, it will be struck when it is just at its central position. Both pendulum and body are held in position, as shown (in Fig. 3), by a stout thread. A simultaneous release is effected by burning the thread at *C*.

The body falls through a measurable distance, and the pendulum occupies a measurable time in moving to the position in which it is met by the falling body. The relation is expressed by the formula, $s = \frac{1}{2}gt^2$.

A thin iron bar about 7 ft. long was used in my own laboratory. A heavy flat disc of lead of 6 in. diameter was attached to this bar, and its upper surface was thinly coated with putty. A central line was marked upon this surface, so as to be at right angles to the path of the falling body. A small round brass body, weighing about 3 oz., was fixed at 8.9 ft.

above the central line of the bob when hanging at rest. The falling body struck the central line exactly true, showing that a fall of 8.9 ft. is executed in .7425 second. The period of the pendulum was found previously by counting the swings made in fifteen minutes to be 1.485 for one complete swing in one direction. To reach its position of rest, only half this time is occupied.

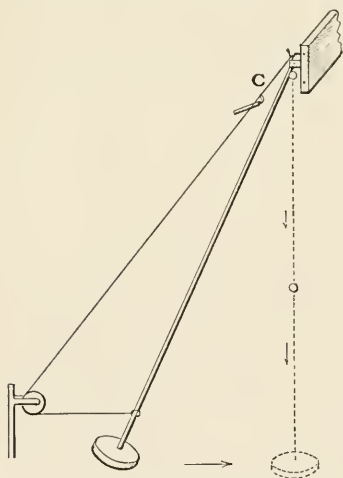


FIG. 3.—Apparatus for determining the time taken in the fall of a body.

The apparatus shown in Fig. 4 is designed to afford experimental proof that the time, taken by a body in falling through a given vertical distance, is *independent of any initial horizontal velocity* which the body may possess, and *independent of the length of the path described*. In other words, the distance traversed by a body before reaching the earth has no effect upon the time taken, for this is only dependent upon the *vertical height* travelled through.

A ball *A* of any material is allowed to run down the curved groove *AB*, so that when it arrives at *B* it has a certain horizontal velocity, which, together with the attraction of gravitation, causes it to describe a curved path *BC*. At *B* the ball touches, in transit, a projecting metal tongue, and this com-

The apparatus shown in Fig. 4 is designed to afford experimental proof that the time, taken by a body in falling through a given vertical distance, is *independent of any initial horizontal velocity* which the body may possess, and *independent of the length of the*

municates with an electro-magnet supporting a ball *D*, so that at the instant the ball *A* leaves the board and enters on its free path, the ball *D* is released from the same level and falls to the floor. It is found that both balls reach the ground at the same instant. A single blow is heard.

The points of difficulty which naturally present themselves to the mind are :

(1) Why the path *BC* should be a curve and not a straight line.

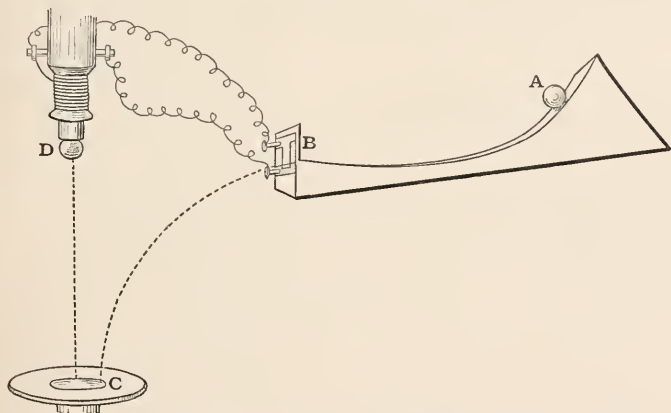


FIG. 4.—Apparatus for showing that the time taken by a body in falling through a given vertical distance is independent of any initial horizontal velocity the body may possess. Compare the paths described.

(2) Why two such unequal paths should be traversed in equal times by similar bodies.

To make clear the first point, it must be remembered that whilst the horizontal velocity of the ball *A* remains constant, the attraction of the earth increases in its effect upon a body, the longer that body is subject to it. It is, in other words, a *force of acceleration*, becoming greater and greater, and causing the ball to assume a more and more vertical direction.

One way of regarding the second difficulty is this:—

Suppose that the horizontal velocity of the ball carry it in

$\frac{1}{n}$ sec. along BN , and that gravity then suddenly pulls the ball down in $\frac{1}{n}$ sec. to M , and so on, as in Fig. 5. The path of the projectile would then be $BNMO \dots C$, the two modes of displacement taking place one after the other. But instead of the effects of gravitation thus following the effects of the horizontal velocity, or *vice versâ*, both occur simultaneously in the body actually falling, and a course such as BMC is always followed in reality. The effects of each displacement are clearly present in such a path, and as the two agents of the displacement are *in action together*, the time occupied is the same as if only

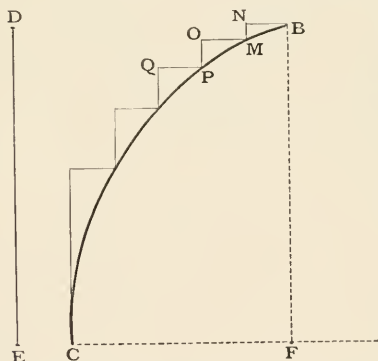


FIG. 5.—Diagram explaining how two unequal paths are traversed in equal times by similar bodies.

one were active. That is, it takes the same time for a body to traverse the path MP as it does to traverse either MO or OP . Therefore the time taken in travelling along BMC is the same as $NM + OP + \dots = DE$.

A path such as MP is usually called *the resultant* of the two forces acting on the body.

It will be apparent that the distance FC affords a direct measure of the horizontal velocity of the body.

Meaning of the term Force.—It will have been noticed that the word **force** has hitherto been used without any attempt at explanation or definition. A convenient definition of force is "*that which changes or tends to change the state of motion or rest of a body, by altering either its magnitude or its direction.*"

It is important to consider the fall of a body to the earth as due to a *mutual action*, or "stress" existing between the two, so that the phenomenon of gravitation may be regarded as the attraction of the earth towards a body, or *vice versâ*, or as both.

Mutual action is usually measured, however, by its action on one body alone, and therefore force is regarded only from one side of its dual aspect. When the term *stress* is used, a recognition of the two aspects of the phenomenon is intended.

Intimately connected with the subject-matter of this chapter are the first and third of Newton's three **Laws of motion**.

1. "*Every body perseveres in its state of rest or of moving uniformly in a straight line, except in so far as it be made to change that state by external impressed force.*"

2. "*Change of momentum is proportional to the impressed force (or impulse) and takes place in the direction in which the force is impressed.*"

3. "*Action and reaction are equal and opposite.*" Action and reaction constitute the two *aspects* or the two *results* of the single fact now called stress.

Quantity of Matter in Motion.—Hitherto the question of speed has been treated as irrespective of the matter engaged in it. It has been considered as a quantity in itself, made up from the two elementary magnitudes, length and time. When, however, we consider matter and motion jointly we have a still more complex quantity, **momentum**. It is frequently necessary to combine together the *rate of displacement* and the *quantity of matter* being displaced, for very striking effects are dependent upon this compound quantity, and, indeed, it must be clear to all, that the extent of the change taking place, when a body moves, needs both motion and mass to be taken into account, if an adequate description of it is to be given. When fully described in this way, it will fall into line with other physical changes.

The numerical value of a momentum is obtained by multiplying the number of units of mass by the number of units of speed. Hence it is said that $M = mv$. This expression is a useful aid to the memory. When once the combination of change with mass is realised, it will be admitted, that a great extension in the classes of quantity to be measured is thereby opened out.

The connection of mass with motion suggests, that mass may also be associated with change of motion or acceleration, and also with rate of acceleration. The last-named quantity, in which the

quantity of matter and also the rate of change of motion are jointly regarded, gives rise to some of the most important results in Physics.

The Temperature of Matter.—Matter is well known to assume different states of temperature. A variation in thermal condition is as familiar as change of position, and, at the same time, there is much that is alike in our way of regarding these two classes of change. All that we know about temperature may be summed up in the statement, that it is that condition of a body which decides whether it shall part with some of its thermal energy to other bodies in its neighbourhood.

We are directly conscious, through our nervous organisation, of differences in temperature. We speak of one state as hotter than another. Rough discrimination of hotness, coldness, and intermediate states is possible. But a scale of temperature, directly based upon our sensations, is in no wise accurate or trustworthy. It is easy to make mistakes as to temperature. Thermal condition impresses us by comparison alone. Our personal judgments are relative to previous or subsequent impressions. And so it comes about, that a moderately warm body will strike us as cold or hot, according to whether the previous sensation was one of higher or lower temperature. Moreover, the discrimination of temperature is confined within very narrow limits. Above a certain temperature and below another, all sensation is alike. A very hot body cannot be distinguished from one still hotter, nor can a very cold body be distinguished from one still colder. In addition, *very* hot and *very* cold bodies give us the same sensation, and they are also equally injurious.

But, as in the case of motion, some fixed point of reference is needed for accuracy of observation to be possible, so in the case of thermal state, no exact knowledge is obtained, until a fixed or standard state of temperature is agreed upon. Fortunately, there are in nature two such **standard temperatures**, to which other temperatures can be referred in a manner, corresponding with our reference to some fixed point on the surface of the earth in measuring motion. These standard temperatures are presented by *melting ice* and *boiling water*.

But in addition to these fixed and standard states of temperature, there is a certain sense of *order*, to be derived from the observation of bodies in an intermediate condition. The same substance can be made to give a *progressive series* of impressions as regards temperature. It may exhibit, either to our own feelings or to the thermometer, a succession of states which must be described by reference to a scale of temperature.

The perception or description of progressive stages of this thermal state or hotness would be impossible without some **scale**, and the establishment of a scale could not have taken place without the existence of standard states of temperature. Between these standard states we have a series of steps, which are denoted by numbers, from the one fixed point to the other. Description of temperature becomes possible by means of these *numbers*, and a definite **thermometric scale** is established. Not only can we recognise when bodies are at the same temperature, as we can by observing that they produce the same results, but we perceive that temperature admits of expression as an order of states, and this order is more exactly described by the creation of a scale carrying numbers.

A little reflection is needed, before it is thoroughly realised, that the statements made above convey no admission as to the possibility of *comparing differences of temperature*, even between similar quantities of the same kind of matter. Strictly speaking, degrees of temperature constitute an order, and do not give an occasion for measurement. We cannot, so far, **measure the intervals** in this order. The expression of the order by means of numbers gives an impression, that this can be done, and erroneous conceptions thereby arise, numbers denoting degrees being added together and subtracted, *as if they were numerical values of quantity*, instead of indicating stages in a progression. *The numbers denoting degrees are different grades of rank, and they are not in any sense to be regarded as quantities.* These distinctions will become more real after practical acquaintance with the thermometer.

Mass and Temperature.—Mass and motion, when considered together, have enabled us to realise the compound

quantity, momentum. It is useful and interesting to compare it with a similar quantity, which may be calculated by combining together in our observation **mass and temperature**. A very noteworthy analogy exists between the two quantities, one being a combination of matter with motion, the other a combination of matter with temperature. A quantity of matter and its state are in each case jointly considered. Yet the thermal state, it must be remembered, is more complex in its nature, and more difficult to measure, than the state of motion; and, moreover, it is always conditional on *quality* as well as quantity of matter.

The new quantity thus arrived at is what is known as **quantity of heat**. There is one respect in which it differs from momentum. *It cannot be measured directly*. The values of a momentum we know to be the product of the mass and the speed ($M = mv$), but quantity of heat, in the sense in which it has, so far, been described, is not the product of mass and temperature. It is a product of mass and *change of temperature*. If the true value of temperature were measurable so readily as speed, it would be a great gain in simplicity of calculation, to take the product of mass into temperature and obtain a kind of thermal momentum. But unfortunately we cannot readily measure temperature from an **absolute zero**, a state in which there is *absolutely nothing* of that condition which confers temperature on a body. There is such a state calculable, but it is not an observable state, as is a state of rest, *the zero from which we measure speed*. In practical measurement all that we can do is to deal with *difference* or change of temperature.

Quantity of heat, then, is proportional to a quantity of matter multiplied by an observed change of temperature. It is calculated, not from absolute temperature, but from the *difference* of temperature which is manifested. Instead of **H** varying as mt , it varies as $m(T - t)$. It corresponds then more exactly with the quantity, which would be obtained by multiplying a mass with a change of velocity. We have seen above that there is an analogy between temperature and motion.

Summary.—1. A given body may exist in a variety of states, and it may pass from one to another. By the aid of

measurements of one or more of the simple quantities already described, alterations in the state of a body may be observed. Our knowledge of such states is based upon the measurement of the simple quantities, length, time, or mass.

2. Matter alone can exhibit states or modes of being. These terms are not applicable to space or time. It cannot be said of time or space, that a change in its state or condition ever occurs.

CHAPTER V

THE MEANING OF NATURAL PHILOSOPHY

IN attempting by the aid of our powers of observation to gain knowledge of the world around us, it is not enough to watch or measure facts by themselves. . It is necessary to perceive, *that facts are connected with one another*. It is essential, indeed, to learn what facts are related, and also *how* they are related. At a very early stage in observation it becomes evident to us, that many changes are connected with earlier changes, or to use a mode of description which is familiar to all, we are aware that many changes are due to, or caused by, other occurrences.

As our knowledge increases we find, that this statement may be extended. It becomes appropriate to say, that *every change* in nature is preceded or accompanied by another, and that no event starts itself or originates itself, for its origin can be traced back through an endless series of prior occurrences. Nothing, indeed, in the inanimate world is spontaneous or self-originated, and the mode of the connection between events forms an important part of the investigation of nature. Perhaps it is not too early to state here, that this is the most important part of our study, as it is the most difficult. It is, in the first place, necessary to ascertain *what events are connected*, and, in the second place, to learn *how they are connected*. And it is this final and crowning effort of the intelligence which renders the use of the phrase, **Natural Philosophy**, a fitting one.

RISE OF TEMPERATURE FOLLOWING FRICTION.

Certain experiments made by Rumford and Davy, at the end of last century, afford an illustration of the manner in which one

change is connected with another, and they happen also to have been the foundation of views which are now very prominent in the practical world. Moreover, a relation between *motion* and *heat* is seen in the fact that motion can produce heat, and it is evident again in the fact that heat can bring about motion.

This is plainly illustrated, whenever motion is produced by means of an engine, through the agency of hot matter—steam, gas, or oil. And the conversion of ordinary visible motion into heat is perceptible, whenever two bodies are rubbed together. The friction of one solid body upon another is soon found to bring about a rise of temperature in each of them. This is more evident in the case of solid bodies—in the friction of a brake upon a wheel, or of an axle upon its bearings in a machine, for example—but the same event takes place, in a less degree, even in the case of liquids and gases. In the case of liquids there is less friction, for material contact is limited, and, consequently, less thermal change than with solids. And gases, through the very small quantity of matter entering into them, provide still less opportunity for friction and for change of temperature.

Illustrations.—Sparks from a flint. The glowing fragments from a railway-break when applied. The hot bearings of an engine in motion. The savage kindling a fire by rubbing wood together.

Rumford produced an indefinite quantity of heat by continued friction, and thus proved that heat is not matter. He had observed, that in the old process of boring a cannon considerable friction took place. It was found that when a horse was employed for 140 minutes in this work, the friction, between the instrument used and the cannon, was sufficient to cause about 19 lb. of water to boil, as well as to raise the temperature of all the bodies concerned in the operation. Rumford states in his memoir: “The source of heat generated by heat in these experiments appeared evidently to be *inexhaustible*. It is hardly necessary to add, that anything which any *insulated* (*i.e.* isolated) body or system of bodies can continue to furnish without limitation, cannot possibly be a *material substance*. It appears to me to be extremely difficult, if not quite impossible, to form any distinct idea of anything capable of being excited and communicated in

the manner in which heat was excited and communicated in these experiments, except it be motion."

Davy found that two pieces of ice when rubbed together gradually melted. He also showed that two pieces of metal, when surrounded by ice, and rubbed together in the exhausted receiver of an air-pump, caused the ice to melt. He attributed the melting in each case to the production of heat by friction, and after some years of consideration, he came to the conclusion, in 1812, that "the immediate cause of the phenomenon of heat, then, is motion, and the laws of its communication are precisely the same as the laws of the communication of motion."

The precise nature of the relation between friction, or work, and heat was not ascertained until the more exact experiments of Colding and Joule were carried out. The searching and thorough investigation of Joule led to a value known as the **dynamical** (or *mechanical*) **equivalent of heat** being formulated in 1849.

The converse change, from heat to motion, though equally certain, is less direct, and, consequently, less striking. The change may appear under circumstances involving disaster, as when a sudden disengagement of heat in a confined space causes an explosion, or it may be *controlled* and *restrained*, as occurs in any kind of *heat-engine*. Here the heat, derived from the burning of coal, gas, or oil, is converted directly or indirectly into motion. Hot gas, steam, or vapour is allowed to enter one end of the cylinder of the engine, and pushes forward the piston. By a mechanical contrivance, called a *valve*, the hot body is next diverted to the other end of the cylinder. The rapid repetition of this course occasions the to-and-fro motion of the piston, and this is converted into the circular motion of the **flywheel**, by a suitable arrangement of constraints, which should be inspected in an actual engine. The motion communicated to the flywheel is handed on, by means of belting and shafting, to places where it may be needed. The whole mechanical activity and movement of most large workshops originates from heat. And the source of this heat is the burning of some kind of fuel, coal, gas, or oil. In some instances, however, the motion is derived from a body of

falling water, as in a water-mill, and in this case a motion already existing is utilised. In other instances the movement is obtained from an electro-motor, that is, the immediate source is an electric one. But in this case, and even in the case where water-power is utilised, the ultimate source will be likewise admitted, after sufficient reflection, to be **heat**.

As illustrations of this we may notice the connection between the water-mill and the wind-mill, which, after all, is a simple one. It is the heat of the sun's rays, which has raised, in the form of vapour, the water from the sea, and deposited it as snow or rain on the tops of the mountains: these replenish the rivers and streams, and so supply the water-mill with its power of working. It is also the sun, which, by causing hot currents of air to rise, sets in motion the winds, thus supplying motive power to the wind-mill.

It is the same radiation from the sun which in old times enabled growing plants to assimilate their food, grow up, die down and, in becoming coal, supply us with a source of heat, which we can utilise for obtaining any amount of power we may wish. The heat which, so to speak, lies dormant in coal is easily converted into steam-power.

It is worth while to notice how the steam-engine, in driving a *dynamo*, furnishes us with an intermediate form of energy, electrical in nature, which can be directed by the use of wires to any position, and can then be utilised for producing motion, light, heat, and chemical action.

The transfer of power over long distances, by means of an electric current, has largely extended the availability of natural sources of energy, for example, that of waterfalls.

A direct transformation of heat into motion is seen in the elongation of a metal rod or a column of liquid, which takes place as the temperature is raised. Here there is a definite displacement of matter, and a considerable disturbance of the previous arrangement and disposition of its invisible parts.

As examples among familiar objects, trace to its ultimate source the motive-power of a *tram* as propelled by electric, steam, and horse power, and carry out the same course for a steamship and for a sailing vessel.

The Communication of Motion by Contact.—When one body knocks against another, the simplest kind of physical exchange or transformation may occur. The motion of one body may grow less or disappear while the other body begins to move, provided it is not too big. Here one physical change, of a very simple character, is definitely handed on from one body to another. Material contact is the sole condition necessary for the exchange to take place.

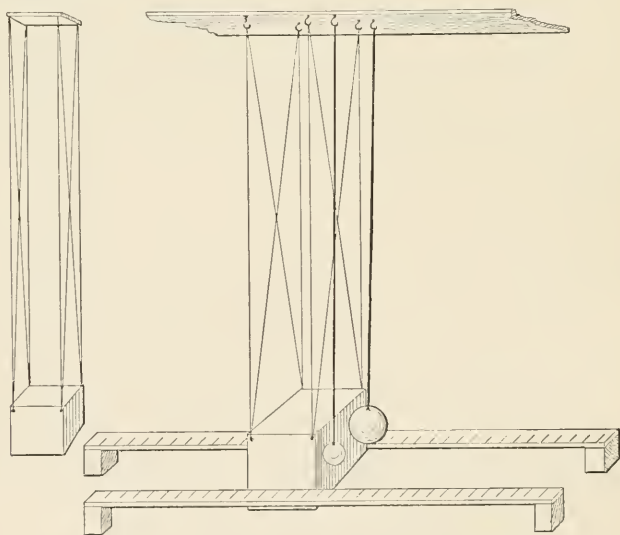


FIG. 6.—Apparatus for experiments on momentum.

But what is handed on is not merely motion. Our experiments will show that the quantity transferred from one body to another on occasions of collision is not motion, but something which is made up of both motion and quantity of matter, and that something is **energy**. It will be found that the complex quantity known as energy is made up of the simpler quantities, matter and motion, combined in a special manner.

The effect produced by a moving body depends upon its **momentum**. The distinction between energy and momen-

tum is best learnt after some practical experience has been gained.

Practical Work.—Two lead or iron spheres, one twice the weight of the other, are suspended side by side. A wooden cube is suspended in the usual manner, shown in Fig. 6, to allow a steady displacement. The spheres are separately put in swing, and the displacement of the cube when struck is observed. Wooden scales may be placed as shown, in order to define the displacement.

Preliminary experiments may be made to show, that the two spheres, if suspended by strings of the same length, swing together, that is, occupy the same time. Also that the length of the swing does not alter the period, for if they are allowed to fall at the same moment from different heights they both pass the vertical position together. A few trials will make this clear. This being ascertained, it is evident that the speed with which either body moves will depend upon *the length of the arc through which it swings*. The speed is proportional to the distance through which the moving body has to pass in one swing, for each swing, whether large or small, has been found to occupy the same time.

The effects produced by each sphere in turn should be noted, both when their speeds are alike and when they are varied. A table of results should be drawn up. It will be found that **the mass of the moving body and likewise the speed have their separate share in the results produced**. In every case, the product of the number of units of mass and the number of units of speed or velocity, give the value called **momentum**, which is always proportional to the effect produced. The distance through which the cube is displaced varies as the momentum. Four ounces, for example, moving at a given speed will produce the same effect as eight ounces at half that speed.

Ballistic Pendulum.—The above experiments may be extended by using Hicks' Ballistic Balance. In this apparatus the novelty lies in the simple ingenuity of the mode of suspension, in which steadiness and delicacy of balance are both at their maximum. For success in this suspension the cords should be as long as the room will permit, and as wide apart as possible at the top.

The illustration (Fig. 7) denotes the method of suspension. The difficulty of adjustment, necessary to bring the two blocks to be in the same plane and to touch evenly, may be readily obviated by using small "runners." The mode of using them is the same as in tightening or slackening a tent-rope. The masses may be varied conveniently, if a pin, to receive annular pieces of iron of equal weight, is fixed through the centre of each block. One, two, or more equal masses can then be added to either block for purposes of experiment. Metallic points may be fixed to one block, so that they are embedded in the other block when a collision takes place. A scale is placed,

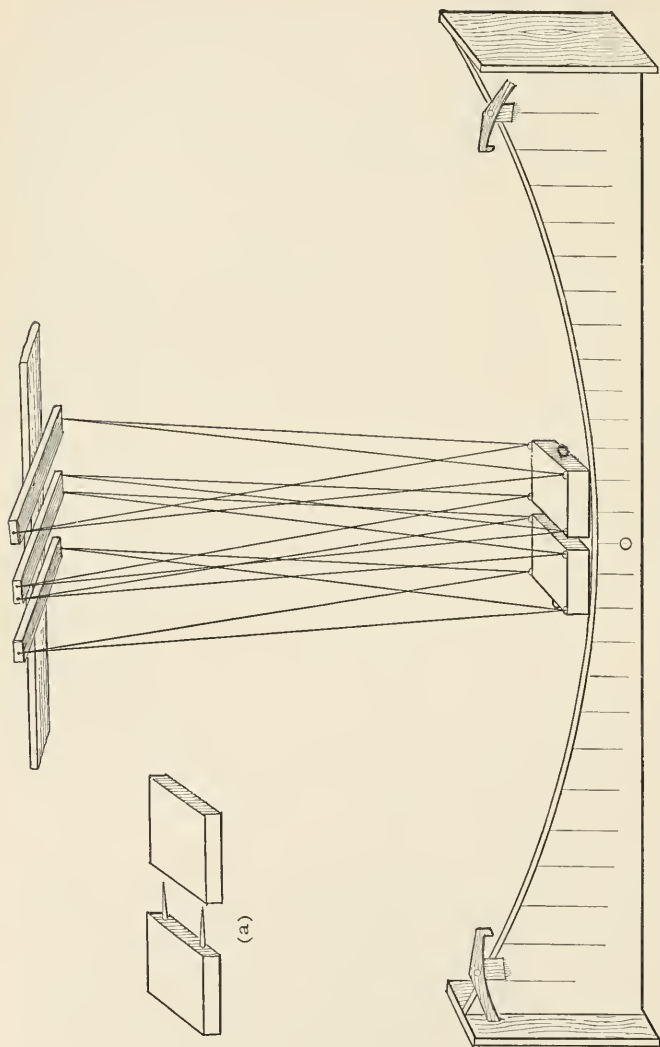


FIG. 7.—Hicks' Ballistic Balance.
a, Subsidiary diagram of the two blocks with metal points for interlocking.

or divisions are marked on the frame of the support, in order to define the displacements occurring.

Observations to be made.—The blocks carrying their varied masses are drawn aside from the perpendicular, by threads fixed to them and passing through the eyelets shown. The blocks may then be simultaneously released, if necessary, by letting the threads go together. Or, better still, a continuous thread may be tightly stretched to maintain the blocks at rest, by the aid of catches. Counterweights, fixed to the catches, fall and release the bodies when the thread is let loose.

It will then be observed, that—

(a) *Effects produced are proportional to momenta.*

(b) *Momenta are proportional to mass multiplied by speed.*

(c) *The total momentum is not affected by a redistribution taking place.*

Vary the masses and the speeds as much as possible, and enter the results in tabular form. It is especially important to note, that the total momentum remains the same (except for unavoidable errors from the imperfection of the apparatus employed) when one block in its motion carries the other along with it. The momentum is now distributed over a larger mass, and the speed is not so large. Also, if the two blocks are arranged to possess the same momentum, and to meet in a vertical position, when going in opposite directions, they will come to rest. In this case, we perceive that **direction** has to be taken into account, in making statements about momentum and its distribution. In calculating the net results of exchanges of momentum, *positive values* must be balanced against *negative ones*.

Additional effects, forming an instructive development in the use of this apparatus, may be obtained by employing blocks on the opposed faces of which the halves of an old billiard ball are fixed. Among other things, the individual movements after impact are to be observed.

Note.—It is worth while considering at this stage, that the handing-on of motion, from one body to another, has many points of resemblance with mutual exchanges of temperature. What is handed on in each case is a joint quantity, into which mass always enters as a factor. A magnitude derived from a quantity of matter *plus* a quantity of motion can be shared with, or conveyed to, another body, and so can that of a quantity of matter *plus* temperature.

It is these compound quantities which give us our ideas of **energy**, energy being always something connected with matter. And their attendant phenomena are looked on as several mani-

festations of the same thing, energy, because it is well known, that during its transfer from one body to another it may change its form completely. *That which is made up of matter and motion in one body or system of bodies may become matter and temperature or matter and electric state in another situation.*

Pressure and Stress.—The effects of pressure are most readily observed in liquids, because of the quickness and completeness with which liquids adapt themselves to new shapes. The simplest effect of stress, however, is that which occurs in the use of a *plumb-line*. A heavy body suspended by a flexible cord shows, by the tightness and vertical position of the cord, that there is a stress between the earth and that body, and that the stress acts in a certain direction. This direction is vertical. The plumb-line is used to mark a vertical position, and it does so because the earth-stress acts in this direction.

It may be pointed out that the reason, why it is so frequently necessary to learn the true vertical direction, is because of this great fact of our existence, the existence of a stress between all bodies and the earth as a whole, and one which is exerted in the most direct fashion, that is, along the nearest route. Every workman, who is engaged in erecting any kind of structure upon the surface of the earth, directs his work in accordance with this fact. He has to take it into account in everything he does, and this is why he consults his plumb-line so frequently. Moreover, every individual, consciously or unconsciously, regulates every one of his movements, and most of his actions, in agreement with this universal earth-stress or **gravitation**.

Existing as it does and being unavoidable, it is as well to give the stress full play, and to make use of it. Its effects upon liquids contained in vessels may be readily studied.

In the first place it may be noted, that when a liquid is at rest its whole free surface is in the same horizontal plane, except where it is in contact with some solid, for example, at the sides of the vessel containing it. Now this is true, even if we have the surface of the liquid broken up into fragments by the shape of the vessel which holds it. For example, the liquid in the vessels in Fig. 8 has more than one free surface, but each part

is in the same plane. This is what is intended to be described when we say, that a liquid *finds its own level*.

Investigate an ordinary spirit-level, and notice that the movement of the imprisoned bubble of air, which decides whether the instrument is horizontal or not, is a result of this tendency on the part of all parts of a liquid to find their "own level." It is only when the enclosed bubble has moved into a position, in which the liquid on each side of it is at the same level, that the bubble comes to rest. The air will always move to the highest point, and if the tube containing it is laid lengthways a diverg-

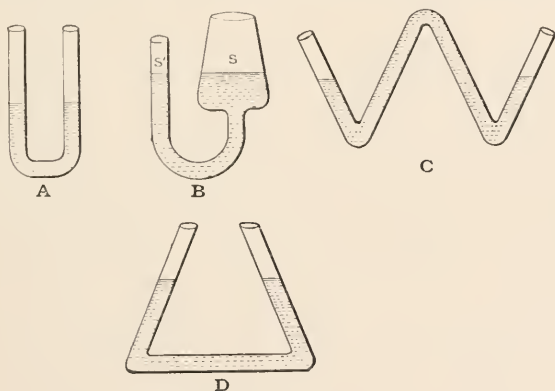


FIG. 8.—Vessels designed to show that each part of the free surface of a liquid is in the same plane, however much it is broken up.

ence from the horizontal is at once perceived. More will be learnt from actual examination and use of this instrument than from description. Notice that it is essential for the tube to be properly set in its case, or wrong inferences may be made.

Equilibrium between the Parts of a Liquid.—The facts of equilibrium, which show themselves whenever the lever and similar machines are in use, appear again in the behaviour of liquids. By watching the behaviour of a liquid, such as water, in irregularly shaped vessels, many facts which are noticed in the action of machines will be encountered. In the vessels A

B , and C (Fig. 8), the surface which is directly exposed to the atmosphere, and therefore to the same pressure, is always at the same level, if all the parts of the liquid are in touch. The parts of a continuous liquid which are exposed to the same pressure will be in the same plane. Now it does not matter how many such parts there may be, nor how various may be their sizes.

In B , for example (Fig. 8), the surface s may be many times larger than s' , yet their level is the same. Moreover, since the liquid is at rest as a whole, the liquid in the thinner limb balances that in the thicker branch. Then we have something in the nature of the liquid, which permits this balancing of apparently unequal parts, just as the lever permits unequal masses to balance one another.



FIG. 9.—Tube with one end closed for obtaining various differences in level.

By using a tube with one end closed (*e.g.* Fig. 9), various differences of level may be obtained. To obtain different levels in the two limbs, it is necessary to displace a portion of the air which may remain within the closed end. This is easily performed by turning the tube sideways, and, if necessary, the whole of the air may be displaced. There is evidently a great difference in the results, when a liquid surface is not *directly exposed to the*

atmosphere, and a little consideration and experimental work will show the reason for the difference.

PRACTICAL WORK.

1. Pour a little water into a U-tube. Note that it stands at the same level in each limb. Add more water, and note that after a few oscillations the liquid settles down to a new but similar level in both limbs. (These oscillations are themselves of interest. It will be found on timing them, that they are of equal period, that is, take the same time.)

2. Use a tube of shape C (in Fig. 8) and note, that an addition of liquid to either branch does not upset the similarity of level. After a few moments, the level will be seen to be alike on both sides. (It affords more certainty to the observer, if levels are marked by a pencil on a strip

of paper fastened on the tube.) Note also that a large quantity of water must be added to the wider limb, to cause a rise of a small quantity of water in the narrower limb.

Here again we perceive an analogy with the lever. The smaller quantity of matter is able to maintain a balance with a larger quantity under certain conditions. The condition in the case of the lever is the agency of a rigid bar turning upon a given point. In the case of liquid equilibrium, the corresponding results are obtained through the form given to the liquid by the vessel containing it. In each instance shape, or relative disposition of parts, is an important feature.

3. Cork up one of the branches of a U-shaped tube and fill that branch by inverting the tube. Add and remove water from the open tube, and note the result.

Satisfy yourself as to the reason, why the water remains in the closed branch, even when most of the water has been removed from the open branch. Is there any limit to this?

4. Use a vessel with limbs of unequal bore, and note the change of level produced in the wider limb, by a given alteration of level in the narrower limb. That is to say, ascertain by observation the quantities of water which balance one another in the two limbs.

To do so, either (*a*) calculate the volume of water which is introduced to each side, by measuring the diameters of the branches, and noting the linear distance between successive levels by the aid of scales placed behind them, or (*b*) add a known volume of water to the smaller branch and notice the elevation of level taking place in both limbs.

It is easy to perceive that this known volume has descended a certain distance after touching the liquid previously present. Were this not so, the difference between the original level and the present one would represent the volume added. In other words, if 25 cubic centimetres were added, then 25 cubic centimetres would be contained between the old and the new level. But this, it can be easily seen, is not the case. We may say, then, that the 25 cubic centimetres of water have moved down through a measurable distance. In the meantime, and in correspondence with this event, another quantity of water has moved upwards through a certain distance.

It is important to measure practically the extent of these movements, and the quantities moved, in this important mutual change, and to perceive that the principle is the same as that of all machines, namely, **the effort expended is equal to the**

work done, when all the components of both effort and performance are considered.

The relative displacements of water are inversely proportional to the quantities displaced. We may consider the water originally present to be incompressible, to be a *species of lever*, in fact, and the quantity raised, compared with the quantity falling, will depend upon the shape of the vessel. *The sectional area of the branches will be perceived, on reflection, to correspond to the length of the arms of the lever.*

In the various observations just concluded, the properties of liquids have been taken as understood, and the effects of the pressure of the atmosphere have been considered as known.

Now the chief facts about all fluids, whether gases or liquids, that concern us in experiments of this kind are:—

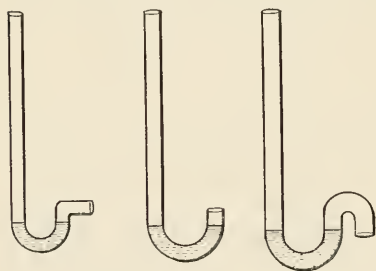


FIG. 10.—Tubes of various shapes for showing pressure to be the same in all directions at the same depth in a liquid.

1. *That the pressure in a fluid at rest increases with the depth, and*
2. *That the pressure is exerted similarly in all directions.*

With regard to the pressure of the atmosphere, the chief thing to remember is, that it is exerted upon everything exposed to it, the surfaces of liquids as well as of solids. Liquids being easier than solids to alter in shape, they are more readily modified by this constant and universal pressure of the atmosphere.

To demonstrate these facts in the case of a liquid, the following experiments may be performed.

1. Bend glass tubing into the shapes shown in Fig. 10, and place some mercury in them to fill the bend, as shown. Notice that the lower the position of these tubes in the water, the farther the mercury is pushed up the long branch, of which the opening is to be kept above the surface of the water. Notice too that it does not matter which tube is used. That is,

the pressure is shown to be the same no matter the direction from which it comes, provided only the depth be the same.

2. It is possible to prove the same point for the pressure of the atmosphere, namely, that the depth of air, or quantity of air above the object, determines the pressure upon it. To do so some form of barometer should be used.

A delicate *aneroid* will show the difference in going from one floor to another, and still more the difference in going up a slight hill. An ordinary *mercury barometer* will stand at a level which varies slightly, but perceptibly, at the top and bottom of a high building. And it matters nothing, how the pressure is received, whether downwards, sideways, or upwards. Though the mercury barometer always receives its pressure downwards, the aneroid reads alike in all positions.

Note.—The word **pressure** must not be confused with the word *weight*. The pressure at any point in a fluid is due, in all the illustrations so far given, to the weight of the fluid above that position. But the pressure on the piston of a steam-engine is not due to weight. Notice also that we are not crushed under the weight or pressure of the atmosphere, because it is the same in all directions, a fact which all fluids exhibit. Inside and outside, and upwards and downwards, the pressure at a given level is the same.

FURTHER OBSERVATIONS OF THE EFFECTS OF PRESSURE, ATMOSPHERIC OR OTHERWISE.

1. Any kind of flexible bag, from which some of the air is expelled by heating, will collapse when cooling takes place, if the mouth be tied. Here the hot air contracts on cooling, fills less space, and the pressure outside crushes the bag. No result occurs, unless communication between the air inside and outside is prevented. If that exchange is allowed to take place, no alteration of shape takes place, for the fall of pressure inside the bag on cooling is soon readjusted by the entrance of air from outside.

2. Show that a piece of paper may be made to keep the water, filling a tumbler, from falling out when the tumbler is inverted.

3. Show that water remains in a pipette, so long as the upper end is closed by a finger. Why does this happen, while the water runs from a wider opening, even if there is no other entrance for the air?

4. Measure the pressure, which is exerted by the atmosphere on a given

area, by observing the dimensions of the column of mercury supported in the barometer. The density of mercury is 13·6, *i.e.* each cubic centimetre contains 13·6 grams, and each cubic centimetre will weight or press upon a surface as much as 13·6 grams.

Note that the manipulation of the barometer, when filled with mercury and inverted in its cistern, brings it about, that there is no pressure from the atmosphere on the top of the mercury column. Indeed, the outer surface of the barometer tube receives the pressure and shields the mercury column.

5. Heat the air in a large flask, and while it is still hot tie a sheet of thin indiarubber tightly over the mouth of the flask. Notice that as the air within the flask cools, the atmosphere presses more and more inwards. The pressure on one side of the sheet diminishes, and is unable to counterbalance the pressure on the other side, as occurs under ordinary circumstances. The equality of pressure from all sides usually prevents the atmosphere pressure being perceptible.

Machines.—All machines are alike in one respect. They may differ very much in appearance, and present a great variety of feature, but they all serve the same kind of purpose. They are all intended to perform some kind of work in the most convenient manner, or rather, they are intended to perform work with *as little inconvenience as possible*. Effort is always needed for the performance of work, and no machine can do away with the necessity of effort, nor can it even diminish the effort required, but it can enable us to apply the effort in a more convenient manner.

The **lever, wheel and axle, and system of pulleys** illustrate this statement. Each of these machines enables bodies to be raised away from the earth more readily than can be done without such assistance. But none of them *diminishes the total effort*, required to produce a given effect, though it may seem to do so. If the lever has a long arm, and the effort is applied at its extremity, the effort needs to be continued for a longer time, or, what is the same thing, over a longer distance, than would be the case with a shorter arm. If you are able, by means of a pulley-block, to raise a body which resists your unaided efforts, you will notice, that the cord which you pull moves through a long distance, while the body moves but little. In fact, each machine enables you, in a fashion, *to do your work in bits*.

Apparatus.—A fairly rigid and hard wooden lath, about three feet long,

is fixed at its centre, so as to move freely in a vertical plane. Any bearing or fixing which is convenient will serve the purpose required. A knife-edge, supplied by an old three-cornered file, passing through the lath and bearing on an iron plate arranged in bracket fashion, or a smooth iron pin passing through the lath and supported in a metal stirrup, made of sheet iron or stout wire,—any mode of support, in fact, which permits of free movement about an axis, will serve our purpose. Wherever this apparatus is fixed, it is advisable to have means of preventing the rod from making a complete turn. As its use will only be to balance one weight against another, some stop should be employed. The rod should have successive inches marked upon it, on each side, starting from the centre of its pivot or fulcrum. This arrangement will enable us to study the principle of the lever.

Experiments.—Suspend varying weights, 1, 2, 4 lb., etc., at varying distances from the pivot, and find the conditions, which regulate the weights and the lengths of arm necessary for the maintenance of balance. S-shaped hooks are most convenient for suspending the weights, and they may be made of copper wire. Vary the weights on each side, and adjust the distances, until equilibrium results. Draw up a table of your results. If a sufficient number of observations be taken, it will be found that the turning effect of a given weight increases with its distance away from the pivot. For example, 2 lb. at a distance of 12 in. balances 6 lb. at a distance of 4 in., and so on.

Conclusions.—Now from this it follows, that a little more than 2 lb. would raise the larger weight of 6 lb. under these circumstances, and all that is needed to obtain a great result from a small exertion is to apply it at an appropriate distance and for a corresponding period of time under such conditions as we have in this experiment.

At the same time it is important to note, that any displacement of the machine here being investigated takes place according to a certain plan or *law*. **The product of one weight into its vertical displacement is equal to the product of the other weight into its vertical displacement.** A little consideration will show, that the vertical movements depend upon the distance at which the weights are fixed with regard to the pivot.

It is easy to show by drawing a figure, and measuring the distances, that the vertical distances are proportional to the length of the arms. This fact is also capable of geometrical proof. And this lesson is by far the most important one which the apparatus can teach us. It is so important that it is worth repeating.

The agent producing the effort must move through a long distance, if the body displaced by it be a large one. The balance of a large body by a smaller one, in this experiment, is typical of every instance of so-called *mechanical advantage* which will ever come before us, and it illustrates an important law of nature. Whenever, to take a familiar example, a crowbar is used to dislodge a heavy weight, which would be unmovable but for this principle, it is evident, *that a small effort moving through a large distance can overcome a larger resistance through a small distance.*

OTHER ILLUSTRATIONS OF MECHANICAL ADVANTAGE.

A lever as shown in Fig. 11 allows the same principle to be observed. Here the two contending stresses are clearly parallel to one another. By

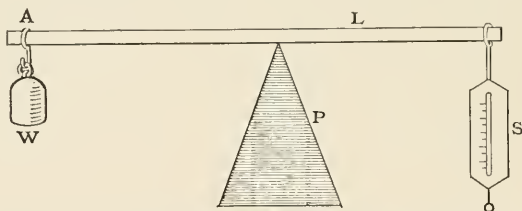


FIG. 11.—Lever and spring-balance arranged to show results of alteration in the weight and in its distance from the fulcrum.

S=Spring-balance. *W*=Weight. *P*=Fulcrum or pivot. *L*=Lever.

fixing a spring-balance as shown, the result of the adjustable and movable mass at *A* is demonstrable. The weight should be varied, and the distance from the pivot or fulcrum changed. The different readings on the spring-balance should be tabulated. The results obtained will impress upon the student, not only the familiar facts about the behaviour of stresses which are similar in direction, he will also notice that the shape and rigidity of the machine brings about similar results, when the stresses are not alike in direction. More information on this subject will be given a little later.

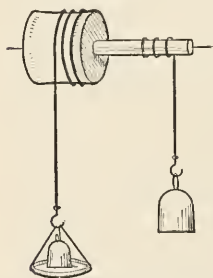


FIG. 12.—Wheel and Axle.

Wheel and Axle.—This machine carries out the principle, which is clearly evident in the action of the lever, that what is gained in one part of a change is lost in another. The weight placed in the scale-pan

connected by a cord with the wheel, as shown in the figure, is capable of counterbalancing a larger weight attached to the axle. The ratio between them is the same as that between the radii of the wheel and axle, provided we neglect the friction of the cords. The diagram (Fig. 12) shows how the stresses due to the two bodies are balanced. The modification of the wheel and axle shown in Fig. 13 is well adapted to display the principle of that machine.

Observations must be made as to the ratio of the weights which are needed in different positions to afford equilibrium, and also as to the relative distances through which two bodies move, when one is just heavy enough to displace the other.

The loads which are in equilibrium will always be those which are inversely proportional to their distance from the fulcrum or turning-point, just as we find to be the case with the lever. Equal masses will be in equilibrium when they are equidistant from the fulcrum.

By multiplying the magnitude of the stress or weight employed in each of these cases by the distance from the fulcrum, we obtain a value which is known as a **Moment** or **Torque**. It is obvious that these values must be equal, and opposite in direction, on the two sides of the fulcrum, if equilibrium is to be maintained.

But the description, here given, of a moment requires amplification. If we balance a weight, acting vertically, against a weight, made to act at an angle (and this may be done by passing one of the cords over a smooth peg so as to displace it from the perpendicular), it will be found by experiment, that the product of the weight (or tension of the cord) and the *nearest or perpendicular distance* of its line of action from the fulcrum denotes the value of the torque or moment.

A Single Movable Pulley.—A movable pulley and a fixed one will together illustrate very readily the advantage to be obtained from the use of pulleys. A known mass is attached to the free end of a cord passing over the pulleys, as shown in Fig. 14, and it is found capable of raising a weight nearly double itself in quantity. The weight raised is evidently that due to the larger mass, together with that of the movable pulley to which it is fixed. But it must not be forgotten that the stress employed has to overcome a certain amount of resistance in the cord which is used. Then taking these things into account, the statement which was made about the lever holds true of the pulley. When there is equilibrium, the stress between the earth and one body is able to counteract that between the earth and

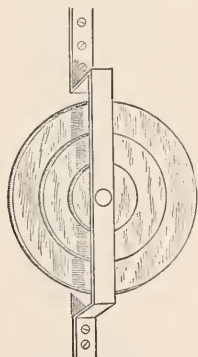


FIG. 13.—Apparatus for demonstrating action of the wheel and axle.

another body, and the arrangement of pulleys and cord consequently plays the same part in producing this result as the lever did.

Various weights must be used, and the facts practically tested. It is important to measure the relative distances through which the different weights move.

Combination of pulleys.—Use the combination of pulleys, illustrated in Fig. 15, and measure the distance through which the free end of the cord must be moved in order to raise any given body a certain distance. When the pulleys in the moving block are three in number, the distances will be found in the ratio of 6 to 1. That is, a big weight moved by a smaller one would only move through one-sixth the distance traversed by the smaller one. Here again it is found, that what is gained in the convenience of being able to overcome a large weight is lost in distance. But it is very important to notice at this stage, that friction begins to be a serious item as soon as a large mechanical advantage is aimed at.

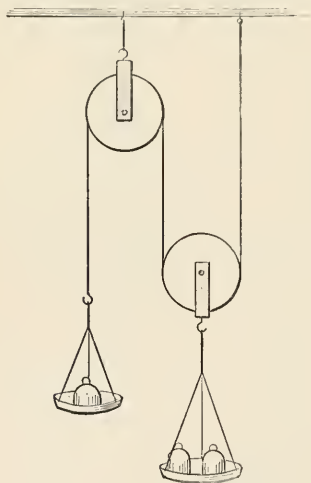


FIG. 14. —Two pulleys arranged to act together.

As more elaborate machines are devised with the view of gaining greater advantage, their aim is defeated by the friction which results from their complicated structure. The area over which rubbing occurs becomes larger and larger. After a time, the loss of energy in overcoming the friction, at the numerous bearings which are needed and at the numerous turnings in the cord or chain employed, becomes very great, and seriously diminishes the calculated gain.

Summary.—In the events occurring in connection with the machines recently described, it is clear that we meet the same

principle in each case. If a given effort or power is to effect a considerable change, it does so by being exerted over a *larger distance*.

The machine presents the occasion for watching and measuring two sides at least of a complicated event. The *total quantity of change* on each side of the machine is the same. Indeed, it would be impossible to understand a given change, when trans-

mitted through any machine, becoming *enlarged* in the process. And, after all, a machine does nothing but transmit a given stress through it.

If the stress grew as it was transmitted, an event quite unlike anything else in nature would have occurred. But it does not grow, it merely changes in form. Or, to be more exact, the components of the mutual changes at each end of the machine are not alike.

The total quantity of each change is the same, but it may be made up of different values in the two instances, and a machine is something *specially devised to separate a given change into such components as are most serviceable and advantageous to us*. As a rule, the distance, through which a stress is exerted, does not inconvenience us as much as the magnitude of the stress itself, and most machines enable us to overcome a large stress through a small distance, by means of a small stress exerted through a distance comparatively long.

THE MANNER IN WHICH A LIQUID HANDS ON THE PRESSURE IT RECEIVES.

The property which liquids have been shown to possess, namely, the ability to transmit pressures equally in all directions, finds important applications in many kinds of **hydraulic machinery**. The mechanical advantage, which

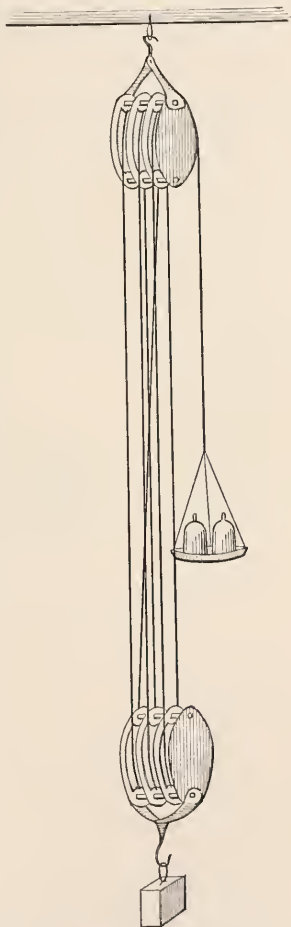


FIG. 15.—Combination of two blocks each containing three pulleys.

obtains in certain cases of transmission of pressure by liquids, may be illustrated in the following way.

A vessel of the shape shown in Fig. 16 is fitted with a piston or plunger, which moves easily, in the smaller branch, and a movable piston in the larger branch. It is filled with water. Now a 10 lb. weight, or a pressure equal to a 10 lb. weight, on the plunger, will be felt over every part of the vessel which is in contact with the liquid. Every part of the surface exposed to the liquid suffers something from the new pressure, and equal areas will experience equal pressures. The pressure of 10 lb. weight on the plunger or smaller piston will be felt, undiminished in quantity, upon each part of the surface of the larger piston, which is equal in area to itself.

If the piston, which is raised by the depression of the plunger (for we may regard the water as incompressible), has a surface, exposed to the water, which is 100 times greater than that of the plunger, then the 10 lb. will

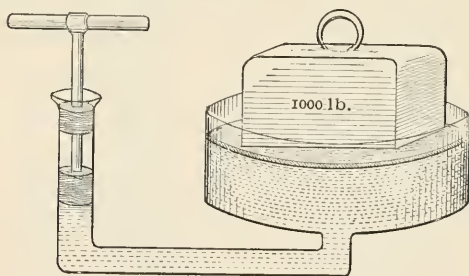


FIG. 16.—Principle of Hydranlic Press.

be able to raise 1000 lb. And this is where the mechanical advantage of the arrangement is gained.

A large pressure, acting slowly it is true, as seen from earlier experiments, may result from the exertion of a small pressure. The weight of the 10 lb. trans-

mitted through the liquid may be able to raise one of 1000 lb., or nearly that quantity.

Apart from what is lost in energy at the joints of the contrivance, from what is lost, in fact, through a species of friction, the principle holds good, and, within the limits of practical mechanical construction, any desired mechanical advantage can be obtained by hydraulic pressure, that is, by utilising liquids for the transmission of pressure. It must not be forgotten, however, that the total effect produced is just equal to the total means employed to produce it, provided every item is considered in each case.

In the **hydraulic press** very great pressures may be exerted by means of the shape and distribution of the water contained in the press, just as the shape of a lever, or an arrangement of

pulleys or wheels, may enable us to exert our available energy in the most advantageous manner. There are, however, few examples of mechanical advantage which cause so much astonishment as the various hydraulic pressing and lifting machines. The explanation of the occurrence must be sought in the properties of the water, as well as in the shape of the vessel which contains it.

CHAPTER VI

CHANGES BELONG TO SEVERAL CLASSES

THE everyday changes that come under our notice mostly belong to one class. There are more changes of position than of anything else. Motion takes our notice more frequently than any other event. Variation of day and night, and of warmth and cold, are striking enough and important enough, but they are usually another manifestation of the fact that a change has occurred in the position of the earth with regard to the sun. Other kinds of change may occur, but the most prominent and the most general are those of *position*.

Next in frequency to these we have changes of *temperature*, and it has been already suggested that these two classes may have something in common. Other familiar events which come under observation in nature are known as *chemical*. They suggest an entirely new kind of occurrence, something more deeply seated, something penetrating more intimately into the substance. The *burning* of coal or wood, the *reduction* of metals from their ores, the *nutrition* of plants and animals, serve as examples of events which belong to a new order.

Displacement, as we understand it, does not seem to be connected with these phenomena. There is some connection with change of temperature, it is true, for not only fire, but many familiar chemical events are connected with heat. Yet on the other hand there is something very distinctive about the facts of *fire*, *acids*, *metals*, *alkalies*, and such things.

Frequently the distinctively chemical character of a change does not at once appear on the surface. The rusting of iron does not show any likeness to the burning of fuel, unless considerable

research is made into each of the changes. It is, moreover, very unlike it superficially in many respects. There does not appear to be any disengagement of heat in the rusting of iron, and the event takes a very much longer time than burning. There is a long process of investigation to pursue before we discover, that the difference in the rate of the changes explains most of the dissimilarity between them.

Now it must not be imagined that changes, such as belong to Chemistry, and others equally mysterious, for example, those known as *electric* or *magnetic* occurrences, are less important because they are so much less prominent than others. They all demand equal attention, and when it has been given, much that is difficult to understand in them will be found to be simplified.

All matter is capable of being displaced, that is, all matter is capable of undergoing a change of position. *The process of displacement is called motion.* Every object that comes under our knowledge undergoes, or may undergo, with regard to some other body, this kind of change. We cannot imagine any body to be immovable. Even the earth, which is frequently looked upon as the symbol of that which is fixed and immovable, is known to be in constant and complicated motion. Bodies on the surface of the earth are fixed only in proportion to their quantity of matter, and, to change their position, a larger or smaller effort is needed. The effort required may be more than can be applied. Still, it is felt to be certain that this, which is called their **inertia**, is the sole limitation. Many bodies do come under the influence of agents which disturb them, and it is argued that all bodies may be displaced under certain circumstances. With a meaning which is precisely similar, we may say, that all objects are capable of undergoing change of temperature. *Everything that we know may grow hotter or colder.*

But when we come to consider other changes an important distinction arises. Not every object can undergo chemical change or electric change, with the same uniformity as they may alter in position and temperature. A *special* and *selective* process comes into play with regard to this kind of event. One kind of object behaves in one way, while another acts differently. In fact, we

come to observe, that **different kinds of matter** exist, and we learn that they are different kinds of matter, by their difference in behaviour under given conditions.

We may state, as the result of our observation in these directions, either that different kinds of matter are known to exist, by reason of their difference in behaviour with regard to certain agents, or that certain classes of change occur in different degrees in different bodies, and in some bodies may not take place at all.

Practical Work.—Observe the melting and vaporising of a little wax on heating. Use a tin tray for the purpose. Melt a little fusible metal under water in a test-tube, and some lead in an iron spoon. Heat a little ammonium chloride in a test-tube, and observe that it passes directly to a state of vapour without showing the intermediate liquid state. A little iodine, too, illustrates the same event.

The above facts represent a large class. **Change of state**, referring specially to a passage from solid to liquid and from liquid to gas, is a possibility with most substances. It is not familiar to us in the case of many substances, because in only a few the change of temperature, necessary to effect the change of state, is one which occurs in nature. The melting of ice, and of a few other bodies, takes place in nature normally. But the great mass of bodies, which do exhibit these changes, are not those which come prominently before us in our daily life. It happens that we are most frequently and most directly concerned with *organic* material, that is, with animal or vegetable matter. This is so complex in composition that many of our statements do not apply to it. One thing is always possessed by this kind of matter, and it distinguishes all organic material. That is **carbon**, and it is simply necessary to take a piece of potato, sugar, fat, wood, or flannel, and heat it in a test-tube, to obtain an indication of its presence. *Charring* soon takes place, that is, the carbon appears.

Everything may change its state with regard to temperature. The change may not appear on the surface. It may be difficult to tell whether a body is hot or cold, unless it be touched, or a

thermometer be used ; but everything, wood, stone, clothes, etc., may vary in this respect, just as everything may move, though the striking change of properties, which occurs in many cases when the range of temperature is sufficiently varied, and is called, with special application, a change of state, may not be possible in the case of wood, clothes, and similar material. The explanation of this lies in the fact, that certain intimate events known as *chemical changes* occur in these substances, before the temperature requisite for a change of state can occur. Flannel or wood, for example, cannot be liquefied, because they cease to be flannel or wood, before they can be heated to the melting-point.

We have here an example of what frequently occurs in our work, one kind of change goes on at the same time as another, and in consequence it is often difficult, and sometimes it is impossible, to ascertain what would be the final result of a given change, proceeding *independently of all others*.

Yet we cannot fail to admit the obvious fact, that all bodies are capable of varying to some extent in temperature. There may be limits placed to this variation by the fact that decomposition, that is, a process of internal disruption, may occur in certain instances, though there are a large number of bodies which may pass, under the influence of heat, from solid to liquid and gas.

In industries and manufactures, physical changes of all kinds are set in motion and controlled, but there is no change which is so frequently encountered, or so important in its effects, as that of temperature, whether we look to the products of civilisation, and natural phenomena, or have regard for our own physical well-being. The acquisition of metals from their ores, the fashioning of metals to useful purposes when obtained, the chain of physical circumstances under which we live, and to which we are so necessarily submissive, that condition of sky and atmosphere which we call weather, and that surrounding of land, river, sea, and mountain which makes for us a boundary to action and encloses our lives, all these things take their form and shape from changes of temperature, and heat is the source of their ceaseless variability and uninterrupted transformations.

Air needed for Burning.—A candle supported on a wire is lighted and placed within a tall glass cylinder. The candle continues to burn as usual. Now close the top of the jar so that the supply of air to the flame is limited to the air inside the vessel. The flame diminishes and disappears. Relight the candle, and observe the effect of admitting air just before the flame goes out. It is interesting also to notice the circulation of the air, when a piece of cardboard forms a partition between the entering and the passing air. The candle will be seen to burn more brightly when such a partition is made.

Observe the change brought about in the air, in which a candle has been burning. Notice that lime-water shaken up in the vessel becomes milky at once, whereas lime-water changes very little when shaken in ordinary air. It may be inferred that the results of burning will be always present to some extent in our atmosphere, and that this is why lime-water is somewhat changed when it is exposed to the air. But the air in which burning has just taken place is very distinctly altered. It must not be assumed, however, that all substances bring about the same change in the air in which they burn.

With precautions, burn a small piece of phosphorus in a small vessel floating on the surface of water underneath a bell-jar. Note that the water rises inside the jar, after the burning is over, and the air has cooled again. The same fact may be demonstrated, by burning, with care and under supervision, a small piece of phosphorus in a vessel closed by a tightly fitting cork. On cooling, the vessel may be opened with its mouth under water. Water will then rise inside the vessel. The flask should be dried carefully beforehand, and the phosphorus may be placed on a piece of asbestos. An indiarubber cork is advisable, or an ordinary cork well soaked in paraffin.

That part of the air which has disappeared is the one capable of supporting combustion. It is called **oxygen**. It has been proved by experiment, that this portion of the air is also a requisite for the life of animals. A kind of combustion or oxidation forms part of their existence. This fact having been settled beyond doubt, it would be an act of needless cruelty to repeat the experiment.

Use lime-water, in the same way as in the last experiment, in the vessel in which phosphorus has been burnt, and it will be found that no turbidity occurs. The products of combustion in this case are unlike those in the latter.

On shaking lime-water in a vessel containing air from the lungs, the turbidity occurs, showing that there is a likeness between the air from the lungs and that in which carbonaceous matter has been burnt. Wax, fat, oil, wood, and paper all contain carbon, and so does the substance of animals and plants.

Although thermal changes may take place in all bodies, and although all kinds of matter are liable to experience change of temperature, all kinds of matter are not alike in their behaviour in these respects. In the case of what is known as **conduction** of heat, a very great variety of behaviour is manifested. Some bodies conduct heat badly or scarcely at all, while others conduct very readily. There are **good** and **bad conductors** of heat, and the process of conduction, that is, the transfer of the quality which we recognise as hotness, varies very considerably, in accordance with the nature of the substance undergoing it. With the same substance and with the same conditions, the conduction takes place in the same fashion, and the manner of conduction is, in most cases, quite as fixed a mark or property of a body as its appearance or any other property by which it may be identified.

Practical Work.—Coat with paraffin, rods of wood (penholder), glass, iron, and copper of about the same thickness, and same length, and pass them the same distance through a cork. The cork is now fitted to a flask full of boiling water and the flame removed. The ends of the rods dipped in the water, and are therefore of the same temperature. It will be found, at the end of a few minutes, the paraffin on the rods is melted through different lengths. On the wood and the glass it may not be affected (a short stick burning at one end is unaffected at the other), while the metal rods will show traces of the transfer of heat, the most rapid in the case of copper. Refinements and modifications of this experiment may be carried out and relative values obtained.

The contact of one body with another of different temperature will bring about results which vary under different circumstances. Some substances will rapidly assume the same thermal state as that of the body which they touch. Such bodies are said to be good conductors. Others, called bad conductors, only come to equilibrium with a body of higher or lower temperature very slowly. The process of arriving at the same temperature, on occasions when bodies are in different states, will vary in speed according to the nature of the substances, and the process in question is spoken of as the conduction of heat. At the same time it must not be forgotten, that the use of the term, conduction of heat, does not imply any real knowledge of what is actually taking place.

When we come to consider another class of event, namely, those which are **electrical**, more marked differences are exhibited by different kinds of matter, and these differences are best realised by actual observation.

Practical Work.—Rub a piece of sealing-wax or an ebonite penholder on your sleeve, and then bring it near to very small pieces of paper. Notice that the body has acquired a property it did not possess before. Perform the same experiment with a glass rod, but use a piece of silk. Show that most other bodies are not capable of acquiring this property, that is, they cannot be electrified by friction.

Consider how this fact may be best described. What has been observed? Small bodies, which are in the neighbourhood of certain kinds of matter in a certain state, are set in motion. Actual contact is not necessary. The *space* around the electrified body seems to be altered. Demonstrate this more clearly by suspending a light body, such as a piece of pith, by a silk thread and bringing the electrified body near it.

This property is lost, when the object exhibiting it is touched all over by the hand, or passed through a flame. By careful insulation, and by preventing contact with the hand, the same state may be induced in a metal.

Use an **electrophorus**. An ebonite plate, which has been carefully dried (moisture preventing the phenomena from occurring) is vigorously rubbed with flannel, and a metal plate with a glass handle is placed upon the ebonite, touched for a moment by the hand, and raised. It will be found capable of attracting the piece of pith or light object. Use a gold-leaf **electroscope**, which will display with greater prominence, by the divergence of the strips of gold leaf, the change which an electrified body induces in its neighbourhood.

Notice that a momentary touch of the hand discharges the metal plate of the electrophorus, whereas a touch with a glass rod held in the hand does not affect it.

It is, however, immediately discharged by a piece of metal held in the hand. Herein we find an explanation of the glass or ebonite handle, which is necessary for holding the plate when it is charged.

There appears then to be a separation of bodies into *two classes*. Those which discharge, and those which do not discharge, an electrified body. More accurate and more extended observations would show, that there is no such rigid distinction, but bodies

vary within an extensive range, and the property which we have to consider resembles the conduction of heat. Some bodies permit electrification to pass through them readily, and are called **conductors** of electricity. Others permit it to pass with difficulty, and are not such good conductors, while others behave in such a way towards electrification, that they are called **insulators**. There exists a maximum of conductivity, and a maximum of insulation, with an indefinite number of intermediate states.

Electrical Conduction.—The process of conduction takes place then in connection with electricity as well as with heat. Events occur in the case of electrified bodies which resemble in some respects those which are observable in the case of hot bodies. It is found that a body changes its state of electrification by contact with other bodies, and at the same time their state is altered. And it is found that *the kind of matter affects the rate and manner in which this change is effected*. The redistribution of electricity among bodies in contact varies in accordance with the kind of matter engaged, in much the same way as the redistribution of heat. Certain changes are dependent in some respects upon the nature of the matter in which they take place, and the conduction or passage of heat and electricity from one body to another affords a good illustration of this fact.

Silk, sealing-wax, ebonite, glass, and many other bodies are noteworthy, since they either prevent the passage of electricity altogether, or to speak more correctly, do not bring about any change in the electrification of a body when brought into contact with it, or else they bring about such changes with extreme slowness. These bodies are non-conductors or insulators; whereas those bodies which permit these changes to take place readily are spoken of as conductors. Metals are prominent in the class of conductors.

But there are other manifestations of the electric state in which a more marked distinction between different kinds of matter appears. This distinction appears in the capacity which some bodies exhibit, and some bodies alone, of becoming electrified while they are undergoing chemical change, or, under certain circumstances, while being heated.

Use a wooden support (Fig. 17) containing two hooks for the suspension of two plates, one copper, the other zinc. The plates must hang so as not to touch. They are then supported by the wooden rest in very dilute sulphuric acid placed in a beaker. Wires are connected by means of binding-screws with the plates, and the existence of a new property is manifested when the wires are connected together and brought near a small suspended magnetic needle.

The existence of a new state of affairs is shown in the fact that bubbles of gas, which were disengaged near the surface of the *zinc*, now appear at the surface of the *copper*, whenever the plates are put in metallic connection outside the liquid, and this the wires enable us to do. Meanwhile the wires themselves, so

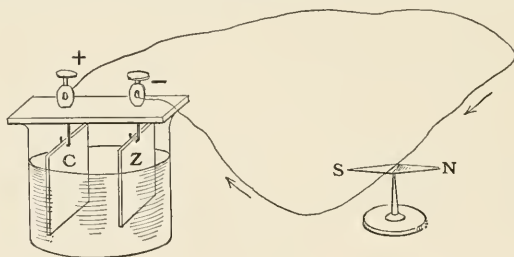


FIG. 17.—Apparatus to show deflection of a magnetic needle, caused by a current passing through a wire.

N=North, S=South Pole of the magnet.

long as they are in contact, are able to influence a magnetic needle, and may be regarded as possessing **magnetic properties**.

If the electrification does not readily show itself by an action on the needle, and the action which should be shown is that the needle tends to set itself across the wire, the effect may be intensified by coiling the wire, so that a number of turns may influence the needle at the same time. In this way a longer length of wire is effective. The same result may be more readily obtained, by having a coil of wire already made up, and a needle suspended in the middle of the coil. This arrangement may be placed in the circuit when needed. It is called a **galvanometer**. *N.B.*—The magnet sets N. and S. by the earth's action.

Further Observations.—Notice that a continuous external

metallic connection is needed for the effects to be apparent. This connecting material, together with the metal plates and the liquid, form what is called the **circuit**. Use a *key*, an instrument often used in electrical experiments, to show the effects of opening and closing the circuit. The system of bodies producing the effects is called the **cell**, and the effects produced form what is called a **current** of electricity.

Many metals, and various other substances, may be used in the place of the copper and zinc here employed in illustration, and various other liquids besides sulphuric acid will serve the required purpose. Matters of secondary importance, and also certain practical considerations, must determine what substances are the best to employ. Leclanché, Bichromate, Daniell, Grove, and other cells should be practically investigated. More is learnt in this way, and the description of them is most useful, if it is made by the student himself in his notebook as a record of his own observation.

The **Leclanché** cell consists essentially of a carbon plate and a zinc rod immersed in a solution of ammonium chloride. The carbon plate, however, is packed with manganese dioxide and carbon in a porous vessel.

The **Bichromate** cell consists of carbon and zinc plates immersed in a mixture of potassium bichromate and sulphuric acid, or in a solution of chromic acid.

The **Daniell** cell consists of a copper plate, placed in a solution of copper sulphate, and a porous vessel containing zinc sulphate together with a zinc rod or plate. All these are placed in an outer vessel, and connections are made from the copper and zinc.

In the **Grove** cell, we have the zinc plate immersed in dilute sulphuric acid, in which is also placed a porous vessel containing strong nitric acid and a sheet of platinum.

The **Bunsen** cell resembles the Grove, except that the sheet of platinum is replaced by a plate of carbon.

Note also, in connection with the effects produced upon a magnet by a current, that it is the *space* in the neighbourhood of the current which is altered. It may be pointed out here, that a stress or a kind of pressure exists near the wire; in fact, it is this **stress** which we perceive, and there is really nothing in the way of a *current* to detect.

But cells, and the chemical changes going on in them, are not the sole source of electric currents. If strips of copper and iron are riveted together, and the junction be *heated*, an electric current will be observable, when the free ends are connected with a galvanometer. Several such junctions, placed together and connected with the galvanometer, will bring about a more marked deflection of the needle. While the junction is *cooling* after being heated, the magnet will begin to move slowly back, and if the junction is cooled in the first place by placing it in ice, the magnet of the galvanometer will turn in a direction opposite to that which it takes on heating.

In the place of the cell in a circuit, we have a mere junction of two dissimilar metals, and, instead of the chemical change which goes on in every cell, the maintenance of the junction at a different temperature from the rest of the circuit, whether by supplying or abstracting heat from it, originates and maintains the so-called current of electricity. It would be a more fitting description to say, that *the maintenance of different temperatures in different parts of the circuit is the source of the electrical energy*.

This is an important association of electric and thermal effects, though the practical value be not great. It becomes still more significant when we learn, that one important result of a current passing along a wire is an increase of temperature. By making a part of a circuit very thin, *i.e.* by interposing a *very thin wire*, the rise in temperature becomes at once apparent to our sense. This experiment should be performed, though the fact is familiar enough in the glow of the **electric light**.

Practical Details.—A **thermo-electric couple**, as the combination of strips of copper and iron may be called, may be constructed of a variety of metals. A junction made, between any metals in the following list, when heated, will cause a current to appear, if the circuit be suitably completed. The farther the metals are apart from one another on the list, the more marked will be the current created, and the metals bismuth and antimony, at the beginning and end of the series, provide the most effective couple.

Bismuth, German silver, lead, platinum, gold, silver, zinc, copper, iron, antimony.

The junction may be riveted, soldered, or brazed. Copper wires for connecting the couple with a galvanometer may be attached by solder. A

number of junctions, combining to produce an accumulated effect, may be conveniently provided by soldering together a number of alternate bars of antimony and bismuth (Fig. 18). Plates of mica are used to separate the faces of the metals, and when fixed in a solid block, alternate junctions are presented on a given face of the block. With a large number of such junctions, the terminal metals of which are connected with a galvanometer, small variations of temperature, occurring on the face of the instrument, are recorded by movements of the galvanometer, and a useful instrument is obtained, the **Thermopile**.

Another mutual relation, resembling very closely that which has just been pointed out, is important to notice, as it is connected with another means of producing electricity, in fact it is the ordinary method of obtaining electricity for *lighting* and for use as a *power* (*i.e.* an agent for driving machinery). You have

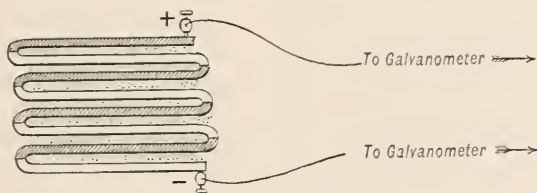


FIG. 18.—Diagram of a Thermopile.

observed that a magnet is turned, or tends to turn, when it is placed near a wire forming part of an electric circuit. The converse of this is seen in the action of a **dynamo**. Here we have a large coil of wire, forced by some power—steam, explosions of gas or oil, or falling water, for example—to turn round very rapidly in the space near a powerful magnet. Instead of the magnet being turned by a current, the turning of a wire in a magnetic field (*i.e.* the space near a magnet) brings into existence the current. A current acts on a magnet, and a magnet can be made to create a current, and this is done by the dynamo.

Magnetic changes are still more special in their manifestations than electric ones. *Very few substances are capable of exhibiting magnetic behaviour.* In the practical world **iron** alone is used, and, indeed, magnetic actions are so unimpressive in the other bodies, nickel, cobalt, manganese, and chromium, that little

practical interest attaches to the fact that they are magnetic. At the same time the phenomena, which do not attract much notice in an ordinary way, may be very significant for those who wish to understand how the events take place, and they may have a bearing upon practice. It is one thing to watch and name events—to say this is a chemical occurrence, that magnetic, and so on—but the process and the manner of their becoming form a far more interesting problem.

A **magnet** is a body which causes a pressure or stress of a special kind near it. The *magnetic stress* is not one which is felt by all bodies, only certain substances, notably iron, are influenced by it. The stress is a selective one, and more narrow in its range of selection than any others we have considered. The *stress of gravitation* is, on the other hand, the most general, and is experienced by every form of matter. The nature of the magnetic stress, the manner in which bodies move under it, and the bodies which are affected, remain for practical investigation.

It will not be forgotten, that light bodies near an electrified body indicate the existence of a stress. The movement of a magnet under the influence of a current shows another kind of stress, or at any rate, another modification of stress, and now the magnetic stress itself selects *certain bodies alone* for its manifestations.

It becomes a question, whether the well-known stress called gravitation has any analogy with these special stresses, or can afford any help in our understanding of them. There is no doubt that we can plainly illustrate the *direction* along which these stresses act, and we can imagine a *possible state of affairs*, which could account for the events observed, if we refer to gravitation for comparison and illustration.

Gravitation makes its effects perceptible in a movement along the path which most directly connects the bodies concerned. A body falls to the earth by the *most direct path*, or as we describe it, falls perpendicularly. It is understood, of course, that no other agent or cause interferes. The statement is only true of gravitational stress, acting by itself and undisturbed by others. The moon does not fall directly to the earth, though there is a

stress, which would produce this result, were there no other action but that of gravitation concerned. Gravitation exists in this case, but it is masked by the high *transverse movement* of the moon.

The stress of electricity produces its effects, as gravitation does, *along the shortest path between the bodies*. It would appear, then, that in both these actions the space between and around the bodies is strained. The ether, an unlimited fluid in which the whole universe is immersed, is supposed to be strained locally, and the result of the strain in this fluid is to press or squeeze the bodies together. In the case of electricity moving along a wire, or in the case of a magnet, the ether of the space around is not strained in the same fashion as in the existence of gravitation. The ether appears to be in a whirling state, and any magnetic substance brought near a magnet, or a wire carrying a current, is under the influence of an ether vortex or whirlpool, which determines the position it will assume.

What kind of pressure or stress in the ether will satisfy our speculative instincts, when we come to consider the event of chemical combination, is difficult to say. It is difficult to avoid the conclusion, that something of the *same mechanism* is engaged in chemical operations as in electric, thermal, and magnetic events. Yet it is not easy to imagine the special modification of the process, which the peculiar facts of Chemistry would render essential, and it is likewise difficult to understand, why certain kinds of matter should permit the remarkable event of chemical combination more readily than others. A satisfactory theory would have to explain the *selective nature* of chemical change.

The features by which we can distinguish *chemical changes* from *physical events* are readily observed. A few experiments will reveal all about them that can be understood at the present stage. All we need for the present is to realise, that there are events going on around us, in which peculiarly subtle changes in substance occur, changes which alter the appearance of bodies so completely in many cases, that they are no longer recognisable. Bodies which have undergone chemical change have lost their *identity*. If hydrogen unite with oxygen, most of the properties, which these bodies possessed before the union, have disappeared,

There is nothing in the appearance of the compound to remind us of its components.

Examples of Chemical Change—Substances gain in Weight as they burn.—A small known quantity of bright lead parings may be used. Weigh a small porcelain crucible, add the lead, and weigh again. Keep the lead exposed to a high temperature, by using a bunsen flame, until it is found to be covered with a yellow or reddish calx. On cooling, weigh again, and note the change.

Place some freshly prepared (*i. e.* freshly reduced) **iron** powder on paper on the pan of a balance, and suspend a magnet from the hook at the end of the arm of the balance. Weigh the whole system. Then bring the magnet near the iron powder, so that most of it may adhere to the magnet. Replace the magnet in position, and then heat the powder by a bunsen flame. The iron glows or burns, and it will be found on cooling that the system is slightly heavier.

The same result may be attained, by placing the iron powder in an open glass tube and weighing. Heat in the flame, and weigh again.

A piece of **magnesium** is weighed in a weighed crucible provided with a lid. The lid is ledged on the crucible, and the latter heated, until the magnesium catches fire. The whole is subsequently weighed. In case there is no increase in weight, what cause can you suggest? With care the increase will be apparent.

Reduce several metallic calxes or oxides on charcoal, by using the blow-pipe. The inverse change will then take place. The oxygen is taken away, and the association of this gas with the metal is disturbed. Use *red lead*, *tin oxide*, and *copper oxide*.

Further illustrations of this class of event will be given in Chaps. VIII. and IX.

Examples of Physical Change.—The practical work which follows has been selected in order to give ample opportunity for the observation of some of the leading facts of physical change. Nothing but a superficial inspection of the facts in question is suggested. Investigations, which lead to quantitative results and involve measurements, will follow these first glances at representatives of some of the changes, which come under the heading of Natural Philosophy.

Rise of Temperature causes Change of Volume.—A copper wire tightly stretched and fastened by a clamp, so that its ends are fixed, is heated. The wire begins to “sag.” It must bend in order to permit the increase in length (Fig. 19),

Arrange two fixed and squared end-pieces at such a distance apart, that a rod with squared ends will just pass between them, but no more. Heat the rod, and it will be found to be too long to pass. (If a lathe is handy, it will provide the end-pieces needed; if not, any two immovable bodies will serve, and an iron or copper rod or wire may be used.)

The same fact is exhibited, if a wire be fixed at one end and allowed to rest at its free end on a small wooden cylinder. On heating the wire, it lengthens, and if it is pressed upon the cylinder by a small body hanging from it, the cylinder will turn as the wire resting upon it lengthens. The turning of the cylinder, which need be nothing more than a penholder, can be exhibited more plainly, by fastening a straw or bristle in it at right angles, as a marker. The movement of the marker may be watched against a scale.

The relative values for the expansion of different solids will

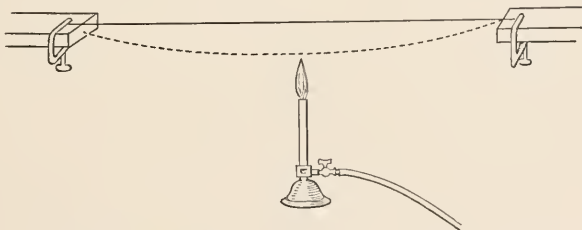


FIG. 19.—Apparatus to show bending due to heat in a wire with fixed ends.

require more careful investigation. In order to compare results with one another, it is usual to reduce the total increase which is observed to the fraction of the whole length. This fraction, when it is brought down to what it would be for a single degree's change of temperature, is called the **coefficient of linear expansion**. For example, an increase of 4·5 millimetres for 90° change of temperature would be ·05 millimetre for 1°, if we assume the rate of expansion to be the same throughout that range of temperature. But the object which furnished this increase in length was 100 millimetres long at the start. Had it been 1 millimetre in length, the expansion would have been $\cdot 05 \div 100$ or $\cdot 0005$. This fraction is characteristic of the given substance, it is one of its distinguishing marks, and is called its *coefficient of expansion*.

But a change of volume is implied in the above changes of length. The dimensions of a solid change in all directions, that is, a **voluminal expansion** takes place, and the linear expansion is only one side of this general increase. This general expansion in all directions is best observed in a liquid, for with its adaptability to any given shape, the increase in volume of a liquid may be made to take a direction which facilitates measurement and comparison.

Use a glass tube, of narrow and even bore, on the end of which a bulb has been blown. Fill the bulb and a small part of the tube with water. To do this, expel a little air by warming. Place the open end of the tube in water, and a small quantity will be pressed into the tube and bulb, as the air within cools. This process may be repeated, until rather more than the bulb is filled. Another process, by which the water may be introduced, consists in connecting the tube by a piece of indiarubber tubing with a funnel supported in a stand. Water is placed on the funnel, and the air within the bulb is heated. Air escapes through the water in the funnel, and water enters to take its place when the residue cools.

The bulb may be surrounded by ice, and the diminution of volume watched by observing the column of water in the tube. The level finally becomes stationary, and may be marked by a thread. The bulb is now placed in a vessel of boiling water, the expansion is noted, and the highest point of the column marked in the same fashion. The vertical distance between these points may be measured and recorded.

A similar experiment may now be carried out, after expelling the water from the instrument, by filling it, successively, with methylated spirit and with mercury. The results may be compared with one another, and regarded as the equivalent changes for the substances in question, provided all the conditions are alike in each case.

Modifications and amplifications of this experiment will suggest themselves.

Expansion of Gases with Rise of Temperature.—A small quantity of mercury is made to enter a narrow tube which is closed at one end. A thermometer is tied to the tube, and the whole placed within a wide tube, which is fitted with corks at either end to maintain the smaller tube in position. The corks carry tubes, which serve for water to pass through the larger tube and around the tube containing the air (Fig. 20). The water which passes through the apparatus may be gradually warmed and the temperature noted. The movement of the mercury may be read off against a scale.

The increase in volume for a given change of temperature will be proportional to the linear displacement of the mercury. The *volume* of the column

of air is proportional to its *length*, provided the bore of the tube be even.

If arrangements are made to include other kinds of gas within the tube, and the same observations be made, it will be found that the coefficient of expansion is in each case the same.

For the same increase of temperature, and for the same volume, all gases expand alike. **The coefficient of expansion is the same for all gases.**

The most marked effect of heat is *change of volume*. The parts of a body alter in relative position during a thermal change.

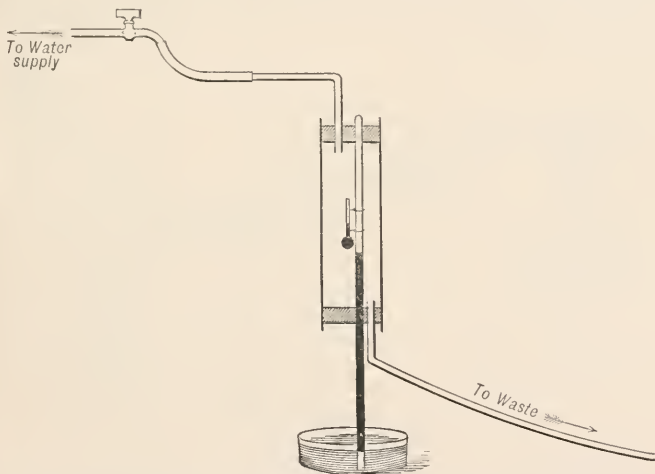


FIG. 20.—Apparatus to show expansion of gases with rise of temperature.

If we are able to imagine, that all substances are made up of small particles, maintained close together and in the same position in the case of solids, and free to move in the case of liquids and gases, then we can consider the most prominent result of a thermal change, to be a *general displacement of those particles*. Hereafter, we shall find strong reasons for believing, that matter is formed of separate particles which are capable of being disturbed.

Change of State—Distillation.—The apparatus needed to show distil-

lation in the case of water and other liquids is well known (Fig. 21). Cold water enters at the lower end of the condenser and passes away from the top. One change of state takes place in a flask or other vessel. The temperature, at which the change takes place, may be read on a thermometer inserted in the cork of a flask. A tube leads away the vapour as it is yielded, and the cooling envelope causes its return to the liquid state. The liquid drips from the tube, and is collected in a vessel. Two changes of state are here exhibited, a *vaporisation* and a *liquefaction*, and the whole is called **distillation**.

Distil pure water from a solution of copper sulphate. Note the difference between the distillate and the original solution.

Distil pure water from a solution of common salt, and note the freedom of the distillate from salt. Bear in mind the importance of being able to obtain fresh water from sea water.

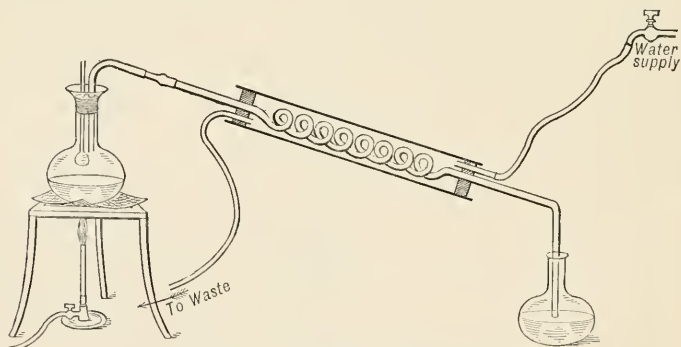


FIG. 21.—Distillation apparatus.

Distil a mixture of spirit and water, and compare the density of the distillate with that of the original mixture. The first portion of the distillate and the portion remaining after continued boiling should alone be used.

Note carefully in each case the temperature at which the first change of state occurs.

We have now learnt, that change of temperature brings about change of physical state. The physical properties of an object change, at the same time as its thermal condition alters. We have already seen how a change of size, or an alteration of density, comes about. The latter event may be regarded as connected with this change of state. Indeed, an alteration of density or volume is a change, which we may look upon as introductory to the

further change, and the theory which has been advanced of matter being formed of small particles will assist us in this conception.

Conduction of Heat.—Press a piece of wire-gauze down upon the bunsen flame. Note the effect. Next, turn out the flame, hold the gauze about an inch above the burner, and light the issuing gas above the gauze. Note that the flame is prevented from going downwards, as it was prevented from going upwards, by the rapid conduction of the metal, which lowers the temperature of the gas below the point of ignition.

Boil water in the upper part of a test-tube, and note that there is very little change of temperature in the lower layers of water. The tube may be held in the hand, if it has been filled nearly full. Water is a bad conductor. Had the flame been applied at the bottom of the tube, the temperature of the water would be much the same throughout. But this would not be due to conduction. It would be on account of the rapid movements set up in the freely moving particles of water, by reason of the constant change of density. This is called **convection**.

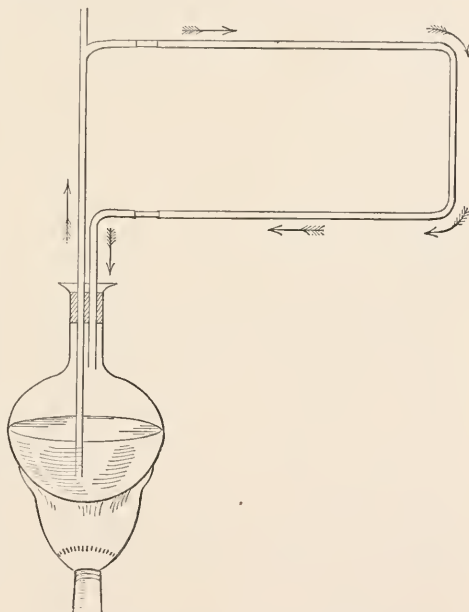


FIG. 22.—Apparatus to illustrate the use of hot water in warming buildings.

Currents due to convection may be shown, by heating water in which colouring matter, such as litmus, has been placed. The water which is warmed becomes less dense, and so rises. The relatively denser water descends from above, and a circulation goes on.

The use of hot water in warming buildings, and the maintenance of the circulation through the various pipes and coils, is illustrated by fixing two tubes in a flask, as shown in Fig. 22. The ascending tube serves as a

means of adjusting pressure, and its equivalent must be provided in every hot-water cistern. The bent tube, which returns to the flask, corresponds with the coils, etc. The flask answers to the boiler. Colouring matter in the water will exhibit the circulation.

The utilisation of the heat distributed in such a system depends greatly upon a mode of transfer of heat, which has not yet been mentioned, namely, **radiation**. Nevertheless, it is a mode of transfer which is of the greatest importance. It is by radiation that we receive heat from the sun, from glowing coal or wood. It is obvious, that radiation occurs without any connection with what we recognise and speak of as matter. Radiation takes place *without material connection*, and so differs from conduction and convection. By the same kind of process, light is propagated from one place to another. The transfer of heat and light is carried on by the same mode of motion, and it is believed to take place as a *vibratory motion* in the substance which pervades space and is called the ether.

Currents in Sea and Atmosphere.—It will be clear after a little consideration, that the effects, which we know to occur in small bodies of water, must be taking place on a large scale in the sea. If large masses of water be at different temperatures in different localities, there will be a tendency for the temperature to become equalised by circulation. Currents will pass over the surface from hotter regions, and colder currents will proceed underneath them to preserve equilibrium. Many causes may intervene to prevent this statement being strictly true, among other things, the conformation of land and the existence of tides, but the tendency always exists for warm water to pass away from hot regions, and for cooler water to enter them.

A shallow vessel, one end of which is kept warm by a flame, and the other end kept cold by a piece of ice, will exhibit this movement. The longer the vessel, the more definite will be the current. If a glass vessel be used, a strip of lead may be bent over the side and allowed to dip into the water. This will serve, when the outer portion is heated by a flame, to warm the water at one end, while the ice should be fastened in its position at the other end. A little coarsely ground litmus placed in the water will display the movement.

We have here, in miniature, a representation of the higher

temperature of the sea in tropical regions, where the earth's surface is turned more directly to the sun, and of the cooler temperate and arctic regions, where the sun, never being directly overhead, has less heating effect. There is a general tendency for warm currents to travel north and south on the surface of the ocean, while more deeply seated colder streams flow in towards the Equator. The alteration in *density*, which ensues with change of temperature, gives rise to these events, and their influence on climate is of the greatest importance. Extremes of temperature are moderated, the temperate regions are rendered more habitable, and even tropical regions are rendered cooler by proximity to the sea. The advantage which accrues to our own country, which is in no part far distant from the sea, is enormous.

The current, from which the British Isles and the western countries of Europe receives benefit, is called the **Gulf Stream**. So vast a quantity of heat is borne from the Tropics by this movement of water, that the mean winter temperature of London is about 21° F. higher than it would be without it. Instead of the mean winter temperature being about 15° F. below freezing point, it is about 6° above it. The Gulf Stream travels from the Gulf of Mexico, in a north-easterly direction, to our shores. It is never more than about 120 miles wide, and it is about 600 ft. deep. When it starts on its course its temperature is about 90° F., and off Newfoundland it is 25° higher than the neighbouring water in winter. The quantity of heat which it brings to us is very great, although it has cooled very considerably before it reaches us.

The direction taken by this current is due to the conformation of the land and the direction of the prevalent winds. The prevalent wind in the Tropics is, on the whole, easterly. A general transfer of surface water from east to west will consequently take place between Africa and South America. The shape of the American continent causes a deflection and a division of this current. The northerly branch circulates in the Gulf of Mexico, and is deflected to the north-east by the North American continent. The account here given must be regarded as a mere indication of the causes and course of this important circulation.

Radiation from the Sun.—The sun is not only the source of our warmth, but is the source of most of those atmospheric changes, which we describe collectively as *weather*. More than this can be said. *It is possible to trace to the sun nearly every change which goes on in nature.* For the present we shall confine ourselves to those changes, which are more directly and more prominently brought about by the sun.

The earth receives heat from the sun by radiation, a process in which matter, as we know it, is not engaged. Radiation is believed to be a vibratory motion of ether, that is, a to-and-fro movement of the fluid, which is present everywhere, though not recognisable by our senses. We are only able to *infer its existence*, from effects like those of radiation. The ether-vibration, when once it is started, is propagated in all directions at an enormous speed. Some of the vibrations of the kind known as radiation affect our organ of sight, and give the sensation we call **light**. Some of them possess a warming effect, and constitute **radiant heat**. All of them, light and radiant heat alike, travel in an evenly diffused wavelike motion at the same speed, nearly 200,000 miles a second.

The effect of this radiant energy, when it meets with ordinary matter, is very varied. A rising temperature occurs, in some bodies very rapidly, more slowly in others. Those which are most rapidly affected are said to be more *absorbent*. Others reflect the radiant energy to some extent, and are, therefore, less readily heated by it. Others, again, permit it to pass through them without being much changed. The most important of this class are gases, and the connection of this fact with questions of temperature upon the earth's surface is clear. *The atmosphere absorbs very little of the sun's radiation.* It is but slightly warmed by the sun, in comparison with the effect produced on land and sea. Here almost the whole of the radiant energy is absorbed, and a corresponding rise of temperature takes place. Scope is now given for the process of conduction. The warmer earth or sea hands on some of its heat to the air near to it. *The air gains by conduction from the earth, not by radiation from the sun.* From this it is easy to see, that the air which is more

distant from the surface of the earth is colder. *As we rise in the air, the temperature falls.* The top of a mountain, being the most distant point from the main surface of the earth, is its coldest point, other things being equal. On the top of high mountains snow and ice are found in the middle of summer, because the higher strata of air being more distant from the general surface of the earth are colder than the lower ones.

The results, produced by the non-absorption of radiant energy as it passes through the atmosphere, together with the heating by conduction of the layer of air nearest the earth, would be more marked than they are, were it not for the wider distribution of heat which is caused by *convection*. We have seen that convection currents exist when a vessel of water is heated in the usual way from the bottom (p. 129). And we have seen, too, that similar currents are formed on a large scale in the ocean. In each case the cause of the current is the change of density produced by heating, together with the subsequent movement of the hotter and less dense portions towards the surface.

Events which are precisely similar take place in the *atmosphere*. But here they are still more rapid and more general, for not only are changes of density more rapidly produced in gases than liquids, but movements, too, are more rapidly carried out, because of the greater freedom of the parts of a gas. For this reason there soon occurs a *very general and even distribution of heat* in the atmosphere, for some little distance above a region which is being warmed by the sun. And, conversely, the cooling takes place through some little distance, when the earth begins, on its side, to lose its heat by radiation at night. For it must be remembered, that radiation takes place, in its proper degree, from all warm bodies, and it is not necessary that they should be visibly hot. A hot-water coil radiates heat, though it does not glow.

Experiments on Radiation.—Two tin vessels are provided (Fig. 23). One is bright, and the other thickly covered with lamp-black. They are both filled with boiling water and the rate of cooling is watched, a thermometer, previously inserted in a cork fitting the mouth of the vessel, being employed. Cooling will be found to be less rapid in the brighter vessel, if other things are alike. The vessels should each be placed on three small corks, so that the cooling takes place as much as possible by radiation.

Place the same vessels, with thermometers in place, and with air alone in them, at the same distance from a fire or in bright sunlight. Any change in temperature, registered by the thermometers, will take place more rapidly in the vessel with a dull exterior, that is, *absorption takes place better in that which radiates better.*

Note.—It might appear that metals absorb more readily than other objects, if we compare our sensations on feeling metallic objects exposed to the sun's rays and other objects placed side by side with them. This inference is not necessarily correct. The temperature of all the objects may be the same, while the best conductors more readily communicate their heat to our body, and so feel warmer. It is useful to remember, that metals and

other good conductors, through the greater readiness in exchange of heat, feel warmer than surrounding objects, when all are equally higher in temperature than our own body; while good conductors feel colder than other objects, when all are equally colder than our body.

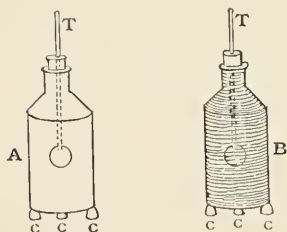


FIG. 23.—Vessels for experiments on radiation.

A = Bright vessel. B = Vessel coated with lamp-black. T = Thermometer. C = Cork.

If the opportunity presents itself, place a penny, and piece of cardboard of the same size, on ice in the sunlight. The penny will melt the ice underneath it fairly rapidly, while the cardboard will not produce any change.

Coat one penny with lamp-black, and brighten the surface of another. Then notice that the brighter one does not sink so far in ice, when exposed for a short time to radiation. There is a difference in the rate of absorption.

A similar difference, not in the absorption, but, conversely, in the radiation, may be observed by using a vessel such as shown in Fig. 24. One half of this is bright and the other dulled by lamp-black. Hot water is poured in the vessel, and thermometers placed at an equal distance away from the two different surfaces. The dull surface is found to radiate more than the bright one, under precisely the same circumstances.

Here we see again, that for surfaces across which radiation is slow, absorption too is slow. *Bad radiators are bad absorbers.* In all these cases, a transfer of heat occurs from inside or from outside, and the same conditions are observed to hold for the

exchange, no matter in what direction it occurs. The names do nothing but show the *direction in which we are looking at the event*.

By interposing screens of different material between a constant supply of radiant energy and a sensitive instrument, a **thermopile** by preference, the absorbent values for different substances are obtained. By carrying out this method of research most of the information we possess on the subject has been gained.

Connection of Radiation with Natural Phenomena.

—Air, which has been in contact with an area exposed to the sun, is warmed by conduction, for it is not warmed by the radiation itself. Its density is consequently lessened, and it rises. This is the most frequent cause of atmospheric movement—the rise of hot air, and, in consequence, the fall of cooler air. But just as in the case of circulation in the ocean, there is much to modify the simplicity and directness of the movements, so in the case of atmospheric currents, we seldom meet with the mere ascent and descent of air. Many things tend to interfere—the movement of the earth in itself is always liable to modify the direction of a current of air.



FIG. 24.—Tin vessel covered with lamp-black on one side to show difference in radiation.

Perhaps the simplest event, which is due to the effects of alternate radiation and absorption of heat, is the existence of **land and sea breezes**. It is well known to those near the sea, that a breeze sets in *from the sea to the land* in the daytime, while a breeze starts *outwards from the land* at night-time. These breezes may be noticed, when other air movements are not strong enough to interfere. A more vigorous and more extensive disturbance may, of course, disguise them.

The explanation is simple. The earth cools more rapidly than the sea, and it gets warm more rapidly than the sea. It is more absorbent, and radiates more rapidly. (In addition to this, the earth has a much smaller *capacity for heat*, a term which has not yet been explained. Water takes more thermal energy than other bodies, to bring about the same rise in temperature. This, too, aids the process we are about to describe.) As a result of the more rapid gain of heat in the daytime, and the more rapid loss at night, hot air rises from the land in the daytime, to be replaced by a current from the relatively cooler region over the sea. In the night-time the opposite action takes place. A current sets in from the more rapidly cooling land, to replace the relatively warmer air as it ascends from the surface of the sea.

Larger operations than these, due to the ascent of heated air on a more extensive scale in tropical regions, take place in nature. Streams of air setting in from cooler regions to take the place of these upward-borne currents give rise to the phenomenon of the **Trade Winds**. These winds, which are fairly constant, may be taken as the equivalents of the main ocean-drifts.

Wherever the atmospheric pressure is *low*, currents of air will set in from places where the pressure is higher, and the winds blow from these quarters. One of the causes of lowness of pressure is a *rise of temperature*. Another cause is the presence of *water-vapour* in the air. The more water-vapour the less the pressure, other things remaining the same, for vapour of water is much less dense than air and does not press towards the earth so heavily. Other causes exist, but they do not allow of simple explanation. The wind which would, under these circumstances, set in from North and South, through diminished pressure in the Tropics, is altered to some extent by the *rotation of the earth*, a rapid turning from West to East. In northern latitudes, an observer would be moving through space from West to East at a high speed. He would meet a wind starting in a northerly direction from a region of lower speed, for it must be remembered that the maximum movement of about 1000 miles an hour takes place at the Equator, and falls away to zero at the Poles. Instead of the North wind, which would be felt if the earth were at rest,

it will blow from the North-East; and in the southern hemisphere the corresponding current will be from the South-East. From their constancy, these currents are of great use to sailing ships, and are called the **Trade Winds**. They are more or less interfered with; through variations in the surface of the land, and exhibit less constancy over land generally, while even on the ocean they are subject to local variations and shiftings for various reasons. A general tendency to blow in the manner described, at certain seasons of the year, is all that can be asserted.

But we have yet to consider what becomes of the warmer air, which has ascended from the Tropics and travelled northwards, or southwards, as the case may be. In time, it becomes cooler and descends. After a latitude of 30° or 35° N. or S. has been reached, and in accordance with the season, this stream descends and moves towards the Poles. In our own country, and in corresponding latitudes, for long periods of the year, this current to the North sweeps over the earth, but it does not come directly from the South. By reason again of the West-to-East rotation of the earth, the wind has an easterly direction added to its northerly one. That is, it blows from the South-West. A corresponding wind, from the North-West, is met with in the southern hemisphere.

Water-Vapour in the Atmosphere.—The change of state, which has been described already as *evaporation*, is constantly going on wherever water exists. It is not necessary, then, to point out that water-vapour must always be present to some extent in the atmosphere. Seas, lakes, and rivers are constantly contributing to the stock. But the quantity in the atmosphere is liable to frequent change. And when it is remembered, that water-vapour is less dense than the air, which it partly displaces, we shall understand that an increase in the quantity present in the air at a given place will bring about a *fall of the barometer*. The mercury must fall, if the average density of the atmosphere is diminished for the time being in the region in question.

A given quantity of air at a certain temperature, however, can only hold a *certain quantity* of water-vapour. When this proportion has been reached, the air is said to be *saturated*, and no more

can be taken up ; into air so saturated no more vapour can pass, and evaporation ceases. But there is a converse change of state constantly occurring, namely, **condensation**, and in the form of *rain, dew, mist, fog, clouds*, and *hail*, condensation exists as an important consideration in the condition of weather. But the causes which bring about condensation are worthy of close attention. They are mainly due to variation of temperature, and they

will be best understood by watching the simple experiment which is now described.

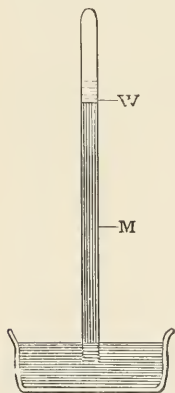


FIG. 25. — Apparatus for showing that the quantity of water-vapour in air increases with the temperature.

M = mercury.

W = water

The Maximum Quantity of Water-Vapour in Air increases with the Temperature.—

A tube, closed at the end, is partly filled with mercury, and is placed mouth downwards in a vessel of mercury (Fig. 25). A small quantity of water is passed upwards, by means of a pipette or syringe. The column of mercury descends. A certain amount of the water evaporates, and this vapour presses the column downwards. If the upper part of the tube and its contents be warmed, by the hand for example, or by wrapping round it a hot cloth, the column of mercury will fall still lower. Now this measurable fall at the higher temperature might be simply the *ordinary effect of heat*, namely, an increase of volume. But by comparing the effect produced when water is present, with that obtaining when air alone is present in the same volume, it will be found that the depression is much more marked, for the same change of temperature, *when water is present*. The inference to be drawn from this observation, though it is not to be regarded as positively justified by the experiment,

is that at the higher temperature more water is changed into the state of vapour. On cooling, the converse change takes place, and water is condensed.

Condensation of Water-Vapour.—When we cool air by suitable means to a sufficient extent, evidence of condensation is at once obtained. On the outer surface of a glass of cold water, which has been just brought into a warm room, moisture soon appears. The cold water and glass cool the air near them, and as the air when cooled is not able to hold so much moisture in it, the excess is deposited as a dew upon the glass.

Blow air by means of a tube through a little ether placed in a metallic vessel with a bright exterior. The cooling produced causes moisture to appear on the outside of the vessel, and the bright surface becomes dimmed. A little ice in a test-tube, of which the outside has been carefully dried, will bring about a covering of moisture upon it.

Observations of this order will help to explain the formation of *dew* or, in winter, of *hoar frost*, when the earth cools at night. The formation of rain follows from the cooling of warm and moist masses of air. Air laden with moisture, even though not saturated, must deposit its excess of water, when sufficiently lowered in temperature, and the deposition may be visible to us either as rain, fog, cloud, or, when the temperature is very low, in the form of snow.

A *mist* or *fog* arises from condensation near the surface of the earth.

A *cloud* is formed when condensation occurs at higher levels.

When condensation is excessive, *rain* appears. The small particles, floating in the air in the case of fog or cloud, are here replaced by drops, too heavy to remain in the air.

But the indirect results of the fall of rain are apparent everywhere, and they are full of importance to mankind. Sooner or late, the vast volumes of condensed water find their way back to the sea, from whence they came. Tiny streams collect together to form the larger streams, and these unite from all quarters, producing by their innumerable contributions the river which enters the sea.

A cycle of changes is here in operation. Evaporation from the sea takes place, condensation occurs, chiefly in the form of rain, which returns to the sea as a river, and the process goes on, and has gone on, without cessation, since the earliest ages. It is a cycle which is never-ending, and in its action, the carving of the land, the formation of hill and dale, mountain and valley, have been going on through the ages. Almost every detail of the landscape owes its origin to this powerful agent, and man, with his wants, his commerce, and his need of protection from the elements, is always under the influence of this closed chain of events. The grandeur of these surroundings, nevertheless, is

magnified rather than diminished, when the student begins to bring all his varied impressions of the world under the scope of general laws, and his intelligence grows active enough to trace, to the operation of a few simple principles, the mighty acts which make up the scheme of nature.

Chemical Occurrences in Nature.—To mechanical action in shaping the landscape, and in carrying down material from higher to lower levels, the operations of rain are not limited. The water which leaves the sea by evaporation is *pure water*, and rain is practically pure water. An experiment already described points to this fact. Yet river or spring water will be found on examination to hold a certain amount of matter in solution.

Experiment.—Boil a quantity of water from a river or spring. If the water comes from a chalk or limestone district, a certain amount of deposit will take place after a time. And if there is no ready deposit on this ground, the complete evaporation of a small quantity of water from a clean glass vessel will disclose a solid residue. A watch-glass will serve for this purpose.

Many substances are dissolved by water, and many opportunities for the process are encountered, as the water passes through and over land.

But there are other important events in nature in which water takes a part. In the first place it forms a very large fraction of the substance of animals and vegetables. In some animals over 90 per cent. of the whole is water. Without attempting to touch upon the intricate chemical changes, which are connected with living matter in its known forms, it may be said that *water is an essential in all these changes*, and its importance is manifested in its preponderating presence in all substances in which life is located.

Experiment.—Heat a few leaves in a test-tube, and notice the large amount of moisture which they give off, some of it condensing in the upper parts of the tube. Heat some animal tissue (meat) and observe the same. A rough weighing will demonstrate the loss, presumably of water, still more clearly.

Water, among other substances, is taken up by *all living things*,

and it is the medium in which occur all the chemical events associated with their activity. Few chemical changes take place under any circumstances, unless one or other of the reacting bodies is in a fluid state (liquid or gas), and water, being so generally distributed, affords, by its solvent action and universal presence, the medium for most of those which go on in nature.

Besides the events connected with solution in water, and deposition from it, the next most important class of natural events is that which arises from the existence of **oxygen** as one of the constituents of the atmosphere. Oxygen, together with **nitrogen**, and a minute quantity of **argon**, make up our atmosphere, but, of these bodies, oxygen alone is *active*, and its activity is very general. When a certain temperature has been reached, it combines energetically with *carbon* and most bodies containing carbon. To this class, *coal*, *wood*, and *all organic bodies* belong. The phenomena of combustion are familiar, but besides the more apparent oxidation which goes on when a fire burns, slow processes of oxidation are going on everywhere around us. Organic matter, that is, matter which is derived from living organisms, large or small, is constantly being oxidised and converted chiefly into *carbon dioxide* and *water*. And in living organisms, too, *a slow oxidation is an invariable accompaniment of life*. Air enters our lungs and combines with some of the carbonaceous matter in our body, and the expired gases contain a quantity of carbon dioxide which was not present in the inspired air. The necessity of fresh air for the life of all animals is well known.

Plants absorb material from the air and soil, and from them build up new and more complex material. Many chemical changes are in progress, wherever there is a scrap of vegetation. **Animals** subsist directly or indirectly upon vegetation, for if they do not always eat vegetation, they devour other animals, which have either themselves been nourished on vegetation or on vegetable-eaters. But the vegetable-eating animal soon transforms its food, and assimilates it to its own nature. Chemical change is here again in progress, varied and subtle in its action.

Wherever life exists, chemical and physical changes are mingled in bewildering activity and profusion. But such are the difficulties in observing them, so deeply seated are they in the substance of the organism, that little more than the bare outline is known of the conditions under which they occur. The *beginning* and the *end* of most of the changes are known ; it is with regard to the intermediate stages that we are more ignorant.

CHAPTER VII

RELATION OF VARIOUS CHANGES TO QUANTITY OF MATTER

Preliminary.—The various classes of physical change, about which something has been learnt, even if only superficially, need to be investigated still further. Moreover, it becomes important to regard them as part of a **general system of change**. A superficial knowledge may still be the result of such investigation, but it will be methodic knowledge, and that is a great advance on possessing only ideas which are unrelated. When a few generalisations begin to be made from very diverse facts, then really valuable and scientific knowledge begins to grow.

Although the chief facts of elementary science are to a great extent recorded, there still remains considerable choice as to the manner and order in which they are to be acquired by the student. The facts themselves are not always important enough to be remembered for their own sake, but they may form part of a scheme of knowledge, and in this case they acquire an additional value. With the object of gaining systematic knowledge rather than storing the memory with promiscuous information, it is a great advantage to be directed along some authoritative plan of inquiry. It is essential also to pay attention to certain of the broader *principles* and *generalisations*, which include many varied items of information or observation, and reduce them to some kind of *order*. It is necessary to observe and dwell upon *similarities* rather than *differences* between two classes of phenomena, and to describe the latter in the most general language that can be found applicable. We shall then learn, that many facts, not ordinarily associated with one another, are in reality analogous, capable of

the same treatment and fitted for the same class. The same arguments may be used, and the same statements may be made, about things which seem at the first glance to be altogether different.

On several occasions it has been necessary to refer incidentally to the manner in which *quantity* enters into all questions of change. But it has been, so far, inappropriate to deal systematically with the relation of mass to the several classes of change which matter may undergo. A statement of the general principles which may be derived from an adequate observation of the facts of change demands more time, and the comprehension of that statement demands more concentrated attention, than could have been given at an earlier stage.

Momentum.—Something is already known about the quantity known as momentum. It is seen to be made up of two simpler quantities, mass and motion. *The number of units of mass multiplied by the number of units of velocity gives the number of units of momentum.* It is necessary to use every one of the words in the preceding sentence. It is very incorrect and quite meaningless to say multiply mass by motion. There is no such process. What we do multiply together is numbers. The product of these numbers informs us as to the magnitude of the momentum in any given case. The **unit quantity of momentum** is that of 1 gram moving with unit velocity (1 centimetre per second) in the metric system, or 1 lb. moving 1 ft. per second according to the English scale.

Observations, described on p. 92, may be repeated with advantage here.

Experiments.—1. A cube of wood about four inches long in the edge is suspended by twine, in the usual manner, to allow a steady displacement. Four small hooks are serewed into the wood, two on each opposite face at the top; thin twine is passed under each hook, and the ends are fastened, some six feet above, to a board as shown. The greater the length of the suspending strings, the more steady is the system. From the same level hang leaden spheres, so as to touch the face of the cube, and to be about fifty and one hundred grams in weight respectively. One should be just double the weight of the other, the quantities not mattering much. A small strip of wood is now ledged, on supports, in front of the cube, to mark the extent of its displacement by the momentum of the sphere.

Draw aside the two shot in succession through the same distance, and note in each case the distance through which the cube is displaced. In other words, mark the effect of *two momenta*, one double the other. The one mass being twice the other, and the distance through which they fall being the same in each case, it is fair to say, that they are each moving with the same speed when they strike the cube.

The time taken in the swing of a pendulum is the same, within narrow limits, however great the *amplitude* of the swing, that is, however great the distance through which it passes in a single swing. Verify this statement, by displacing the two pendulums (for they are both simple pendulums) through unequal distances and letting go at the same instant. They will both *pass through the vertical position at the same time*, and continue to do so at each swing. From this it follows, that the speed must be proportional to the amplitude of the swing, for each swing has to be performed in the same time. If a pendulum is displaced through two feet, it will strike the cube with twice the speed, possessed after it has been displaced through one foot.

A number of observations should now be made, varying the *speed*, and trying both the *masses*. A table of the results obtained should be drawn up. Among other things, it should be proved, that the smaller mass, moving with a given speed, produces the same effect as the larger body, moving at half that speed.

A further variation may be introduced into the experiments, which may be performed with this apparatus. The distance, through which the cube is displaced, will depend, other things being unaltered, upon the mass of the cube. The effects produced by placing additional masses of known value upon the cube should be observed, and they are especially interesting at the present stage of our course.

2. Two blocks of wood are suspended in the same manner as in the last experiment. The longer the suspending cords, the better the results. To add to the evenness of the swing, stays are fastened to the blocks. These must be firmly screwed to the blocks. The cords have to be adjusted, so that the blocks hang level, set in the same direction, and are maintained horizontal when displaced. For this adjustment, which is important, it is convenient to use miniature "runners," on the principle of those employed in pitching a tent. The blocks serve to carry additional masses, and since the impact may displace a body which is not fixed, it is well to employ annular masses of iron, of equal weight, which pass over a piece of iron rod fixed in the centre of each block. They may be cast for the purpose. Each block may be leaded, if necessary, so as to equal in weight one of the iron masses. This will enable masses in the ratio of 1, 2, 3, etc., to be employed.

The object of this apparatus is to enable various momenta to be balanced against one another and, indirectly, to enable masses to be measured by the

momenta generated with a given speed. By varying the masses, and adjusting the distance through which they are displaced, the desired effects are produced. The speed with which each is moving at the moment of impact will be proportional to the distance, through which it has been moved from its position of rest before being released.

It is an advantage for most of the experiments to be performed with this apparatus, that the blocks should adhere on impact, so as to permit the immediate redistribution of momentum to be more readily observed. For that reason either a spring catch is fixed to the opposing faces, or, on the one a piece of soft wood is glued, and on the other a piece of wood carrying two sharp points.

Suggested Observations.—Employ equal masses, and show that there is no movement after they meet at the centre, when they have been equally displaced. The momenta are equal, but opposite in direction, and they balance one another. Equal masses moving at the same speed have the same momenta.

Employ masses in the ratio of 1 to 2, but allow the smaller mass to move through twice the distance traversed by the larger. They come to rest on meeting, since the momenta are still equal, $mV = Mv$. Also use masses in the ratio of 1 to 3, and allow the speeds to be as 3 to 1.

Ascertain the magnitude of an unknown mass, by finding out the distance through which it must be displaced, in order to balance the momentum of a known mass moving at a given speed. The masses are inversely proportional to the speeds, and the speeds are proportional to the distances traversed on release.

The observations, which are here described for the second time, give a more definite meaning to what our muscular sense tells us vaguely. We are in the habit of gauging the quantity of matter in an object before us, by the muscular exertion needed to move it, by the intensity of the “push” we have to give it. We estimate quantity of matter by *lifting*, *pushing*, or *rolling*. Each action brings into play muscular contractions of the same kind, and we are sensible, within certain limits, of the extent of these contractions. We have a sensation for quantity of matter, which is as real as the sensation of sight or hearing, though it is not so accurate as they are. It is noteworthy, however, that the limits of our muscular sense are as restricted as our muscular energy. Those masses, which we are unable to move, remain entirely unknown, except by vague estimates from size.

Inertia.—The sense of mass, as something possessed by all bodies, is the origin of the term **inertia**. *The magnitude of the*

resistance, which a body presents when we attempt to move it, gives rise to the value known as inertia. It does not matter what the movement may be, under similar conditions the greater mass has the greater inertia. We describe a resistance to change by this term, and inertia may be intelligibly described as the tendency to remain at rest, to be inert, though it is better to regard inertia, as that property by which matter makes itself known to us, and known to us in varying quantities. **Inertia and quantity of matter** may be regarded in many respects as equivalent terms.

It is important not to confuse the action of *lifting* with that of *pushing or rolling a body along a smooth surface*. If we lift two bodies through the same distance, the effort exerted gives an indication of their masses, but to lift one, and roll or push another, does not give an opportunity of comparison. The two classes of change are different, for in lifting we have to contend against the earth-stress or gravitation, as well as the inherent inertia of the body.

The **inertia** of a body is always part of its existence, and the property which goes by this name will be recognisable, however situated the body may be. The stress which pulls a body to the earth is a fact quite distinct. Its value depends upon the earth itself. Gravitation on the sun or moon is a very different thing. On the moon, which is much smaller than the earth, a given body would "weigh" less, would be attracted to the moon less than it is to the earth. On the sun, however, which is much larger than the earth, the mutual attraction or stress would be much stronger. The body would "weigh" far more.

But whether on the sun, moon, or earth, the inertia would be the same. The effort required to set it in motion would be the same, and if, by chance, we met the body in space, infinitely removed from all other matter, where no attraction in any direction existed, it would still have its characteristic inertia. It would still want the same effort to move it, as it did when on the surface of the earth. All that would be changed would be its "weight." It would have **no weight**, that is, no drag in a certain direction. It would not be pulled in any way. It would be free to move in

all directions equally. But it would offer a resistance to motion, due to its unchangeable inertia, in all directions equally.

Illustrations.—The effect produced by a moving body does not depend upon its weight or downward pull to the earth, for we have seen that these effects are produced, when this pull is counteracted by supporting a body on strings. Yet the inertia-effect and the weight-value will always have the *same relation to one another* in different bodies.

A body moving rapidly upwards, a shot fired in the air for example, will have an effect, which depends upon its speed and its mass together. This effect will be the same in whatever direction the body be moving, and it would be the same whether it happen near the earth or away in space.

A large stone to be set in motion upon ice requires an effort dependent upon its mass. There is no question of weight here, for the surface being horizontal, weight or pressure to the earth does not come into play at all. It is neither resisted nor utilised.

A barrel has to be rolled over a smooth and horizontal pavement. Its inertia, dependent upon the quantity of matter present, has then to be overcome. A kick will tell us whether a barrel is full or empty, and the same information might be gained, by the same process, if the barrel and the observer were placed in space far removed from any other attracting matter.

Summary and Conclusions.—Enough has now been said to emphasise the fact that the mass and the inertia of a body are invariable values, *which cannot be altered by any change in its circumstances*, whether of state, condition, or situation, whereas the weight of a body depends on the proximity and size of the *neighbouring bodies*. All our direct and certain knowledge has reference to the earth, as the origin of gravitation; but by means of inference and reasoning, that which approaches very closely to certain knowledge is gained concerning gravitation-effects, varying in value and extending to the whole of the universe. The different members of the solar system, our earth and the other planets, are believed to be retained in their orbits on account of a mutual action between themselves and the sun, which is the central and more stable member of the system.

But attention must be given to another feature in the facts described in this chapter. Momentum has been stated to be a product of matter and motion alone. Inertia too is the test of the existence of all solid matter. In no instance does the question

of *kind of matter* come under discussion. What is true of one kind of matter is true of another, with regard to these points. The inertia of 10 lb. of copper is the same as that of 10 lb. of butter. The gravitation, too, of 1 lb. of lead is the same as for 1 lb. of feathers. Quality or kind, as distinct from quantity, may be ignored on these occasions.

But matter in general is not easy of comprehension. In discussing any changes which are independent of the kind of matter engaged in them, something more than ordinary notice is needed to grasp their full meaning. The difficulty in apprehending their import is mainly due to the fact, that they are part of a larger scheme of activity than has been previously treated. The ideas involved are wider, and their application is more general. Their application, in fact, is universal, and in confronting for the first time conceptions of the highest degree of generality, the student may find himself incapable of realising their full meaning. It is only by repeated illustration and frequent impression, that the words formulating such comprehensive thoughts convey their proper value to his intelligence.

Still another aspect of inertia remains for discussion. So far we have dealt with bodies at rest, and considered the effort necessary to move them. But what do we mean by a body at rest? Do we know any body which is absolutely at rest? As a matter of fact the words "at rest" relate solely to the earth. An object which does not alter its position with regard to the earth is at rest. But we know that the earth and the body upon it are actually in rapid motion, and the question may naturally be asked, whether our ideas about inertia can be made to apply to matter in the state of motion.

A little reflection will enable us to understand, that when we move a body upon the surface of the earth, we do not move it from rest, but we *change its motion*. And if we alter the wording of each description of inertia already given, and substitute "*alter the motion of*" for "*move,*" we shall have gained a better understanding of the situation. The magnitude, which we call the inertia of a body, is just the same, whether we estimate it from the effort required to move it from its position on the earth's

surface, or from the effort required to change its motion, when it is moving with regard to the earth's surface. In each case a change of motion is produced.

The effort required to change the motion of a body depends upon its inertia. The same thought is conveyed by saying that it depends upon its mass. These statements cannot be studied and reflected on too carefully.

By a slight change in the course of our thoughts, we may pass from one side of the question of inertia or mass to another. We may consider that there is something which changes the motion of a body. There is, indeed, always something which does change it. There is always, somewhere or other, a change corresponding with the one we are watching. **No event occurs alone by itself.** If we have the necessary skill, we can trace it back to some previous event. Somewhere, perhaps close at hand, there must be another event to "explain" it, as we say. This desire for explanations brings us to look upon every event as produced by an agent, and these agents are called **forces**.

A force is the agent invented to explain a change of momentum. We can never observe force, for there is nothing to see. All we perceive, in connection with force, is a change in momentum, or, to be more accurate, a rate of change of momentum. And this is a measurable change, and so gives rise to the idea of force as a quantity. We do not measure the magnitude of a *force*, we observe change in the *quantity of a momentum*. And somewhere else, in most cases close at hand, there is some event to correspond with the first change, and this is connected with another, and so on, in an unending series.

Various Sources of Energy.—The energy of a *strained body* is perhaps the easiest to understand. Energy is given to a body by deforming or straining it. A spring is stretched or compressed, or in some fashion altered in shape. An elastic body is stretched, bent, or compressed. Steel when deformed, as in a clock spring, indiarubber when stretched, air when compressed, all represent bodies to which **energy** has been given. They are in a more energetic state, because they have been altered in shape.

They are capable of bringing about changes in bodies in contact with them.

A *hot body* is in an energetic state, bodies touching it may be affected, indirectly or directly, so that they move. The compressed steam in the cylinder of a steam-engine expands because it is hot, and moves the piston in expanding. There is no need to dwell upon the importance of this source of energy.

But *electrified bodies* are also among those which are in a special state, rendering them capable of doing work, and so are bodies which have a certain composition. An electrified body at rest, when it has acquired a change of electricity by friction, or by communication with a body already changed, may possess no very marked capacity for affecting other bodies in the way of performing work on them. But when a large quantity of electricity is *being transferred* along a conductor, the conductor may be capable of performing a large amount of work.

To achieve this work, the conductor, conveniently a copper wire, is connected with an *armature*, which is placed between the poles of an *electro-magnet*. The current, or electricity in motion, passing into the armature, causes it to rotate, if it be provided with proper axle and bearings. In principle, what is needed is the construction followed in the dynamo. If the current be then led into the armature, instead of being taken away from it, rotation takes place, and the mechanical energy may be handed on by belts and shafting, whereas the forcible rotation of the armature creates the current in the ordinary use of the dynamo. The machine, so used to convert electric energy into mechanical energy, is called an **electro-motor** or, shortly, a **motor**.

Coal in virtue of its *chemical state* is a source of energy. It may burn, convert water to steam, and the steam by its expansion may drive an engine. Zinc is another example of a chemically active body. It may be consumed in a cell, assist in the formation of an electric current, and this may be utilised in various ways. The lead in an accumulator, or secondary cell, is chemically acted on, and, by its association with other substances present, it produces an electric current. Elementary matter is a valuable source of energy, and material in this advantageous condition loses

its energy on undergoing chemical combination. It is, in fact, a state of isolation or freedom from chemical alliances, which gives matter of a more or less elementary character its possible or **potential energy**.

One of the most important as well as most interesting parts of a student's work in the future will be to consider, in what forms energy may be *stored*, and in what quantities it exists in various stores. The largest supply of energy at the disposal of mankind is in coal. If the "*head*" of water produced by tidal movements could be utilised, as waterfalls are used, the supply of available energy would be enormously increased.

Kinetic Energy.—There is, however, one prominent form of energy which must monopolise our whole attention at this point, and this is the form of energy which a body possesses in virtue of its motion. It is called **kinetic energy**. It seems strange at the first glance, that we should discuss different classes of energy, before we know rightly what energy itself is. But this is not an uncommon experience. We cannot imagine that we really know what matter is, and yet we have no hesitation in talking about different kinds of matter. It is possible that we may learn what energy is most satisfactorily, by investigating its chief forms in succession, but for the moment we are wholly concerned with the properties shown by matter in motion, and due to motion alone. In connection with the kinetic energy of a body, we have no need to consider any other fact or capacity but speed. It is matter in motion, and in consequence of its motion it is energetic matter.

We may regard the effects, produced by a body in motion, as evidence of a capacity which may be compared with its thermal or electric capacity. But this kinetic capacity differs from all others, in being absolutely independent of the other properties possessed by an object. It is dependent, for a given speed, upon quantity of matter alone. *It is never influenced by the kind of matter, as other physical capacities are found to be.* Given a certain motion, the same effects are produced by a given quantity of matter, whatever its nature may be.

This condition was found to exist in the case of momentum,

But we now begin to deal with something which is distinct from momentum. A body moves, because another body has been in contact with it, or is now pressing upon it. *The exertion of pressure on any object through any distance is the performance of work.* To do work is to exercise a pressure over a space. The pressure must act through a certain distance, or no effect will be produced; the body on which the work is done must change its position or its shape. The longer the **distance**, the greater is the amount of work. Also, the greater the **pressure**, the larger the amount of work.

If the body do not move when it is acted on, yet it gains additional energy all the same, but not of the kinetic or visibly moving form. It is then described as having potential energy. A stretched or compressed spring, a compressed gas, a heavy body pressed up from the surface of the earth, are examples of bodies possessing potential energy. But whether the energy be in the kinetic or potential form, the body is known to have it in possession, because it can exert pressure upon another body in turn. It can hand on something to another body. It can do work upon it, and this other body can do work upon another. What is handed on from one to the other is **energy**. *And the act of work is the transfer of energy.*

When energy has left one object and appears in another, its *form* may have changed, but whatever may be its form, it is always recognisable as a quantity which has two factors, and one of them is, as a rule, a quantity of matter. It is measured as a certain quantity of matter moving at a definite *speed*, a certain quantity of matter at a definite *temperature*, or a certain quantity of matter under a definite *pressure*.

Illustrations of Kinetic Energy.—An object is safely supported by a thread. Raise the body and allow it to fall. The thread is broken. It is incapable of resisting the increased energy of the body. It breaks in the attempt to destroy that energy.

Suspend a body by a string from a spring-balance. Note the extension of the spring. Raise the body, allow it to fall, and notice the increased extension of the spring when the motion of the body is checked. The work done on the spring is greater when the body is moving, than when it is at rest.

A body allowed to fall upon the pan of a strong spring-balance will be found to increase the compression of the spring, as the distance of its fall increases. Sawdust should be placed on the pan to prevent vibration and noise.

Now as regards the last experiment, it may be noticed, that the time during which a body has been falling (or the length of its path) is a *measure of the speed* attained at the end. By *doubling the distance* of the fall the speed is made *four times* greater, by *trebling the fall* the speed is nine times greater at the end of the path. But it will be noticed, *and this is a point of very great importance*, that twice the compression is produced when the distance is doubled. In other words, the speed must be quadrupled in order to double the work done. This is the distinctive feature of kinetic energy. It is, for the same mass, proportional to **the square of the speed**.

It may be thought, that this fact is not clearly proved by the experiments already given, for the action is complicated by the existence of the earth-stress. But the stress between the earth and a body in motion may be overcome or avoided. The body may be rolled along a smooth horizontal surface. Here too we should find, if the speed could be measured, that the work done by a moving body does not increase directly with its speed, but with the *square* of the speed.

This may be shown more conveniently by noting the compression produced in a spring, when a body suspended by a string is allowed to strike against it. In this case the string receives, and counteracts, the pressure exercised upon the body by the earth. The speed with which it is moving, as it strikes the spring, may be varied by altering the amplitude of the swing of the body. Each swing is performed in the same time with string of a fixed length, and therefore a longer swing implies correspondingly greater speed. The face of the spring should be placed, so that it is struck by the body when it is at the centre of its swing, that is, when the string is vertical. The compression, in this case, is doubled, when the angle through which the string is displaced is made four times larger. *The effect is proportional to the square of the speed.*

If the compression on a graduated spring is the same as would

be produced by a weight of 20 grams (*i.e.* the earth-stress on 20 grams), then to compress it to the same extent as 40 grams, the speed must be quadrupled instead of doubled. Care and quickness of observation are needed, in order to read the instantaneous movement of the index of the spring.

The quantity of kinetic energy is proportional to the product of the number of units of mass and the square of the number of units of speed.

It is independent of kind of matter.

Both these statements may be demonstrated, by varying the mass and the kind of matter in the above experiment.

Quantities and Chemical Change.—The alchemists and searchers after the philosopher's stone, busying themselves with the transmutations of substances, the production of precious metals, and the discovery of the elixir of life, were never limited in their speculations, as we are, by considerations of quantity. The growth of a substance in gravity, or the appearance of new matter where none existed before, always existed as a possibility for them. There was nothing in their theories or knowledge to contradict the belief, that such events might happen. But when attention began to be turned, to inquire whether a given change made a body lighter or heavier, it was soon felt, that knowledge of quantity might afford a clue to the nature of many mysterious occurrences. And this was especially the case with the phenomena of fire and burning. It was during the more thorough investigation of these things, that the value of the **balance** as a means of research became prominent. In the course of time, the employment of the balance became a habit, and a body of information was soon amassed, which was destined to throw much light upon many difficulties and to clear the way for the rapid development of modern science.

The discovery of **oxygen** was a great triumph for the balance. And it was not only the discovery of oxygen, first of all by Scheele in Sweden in 1774, then in the same year, and independently, by Priestley in England, and slightly later by Lavoisier in France, that was effected by the use of this instrument. From that period began the establishment of a new science, modern Chemistry.

Priestley and Scheele both found, that there were certain substances, Red Lead, Calcined Mercury (also a red substance, now called oxide of mercury), and Nitre, which, when heated, gave off what they called *fire-gas*. Lavoisier repeated the experiment, of which he had been informed by Priestley in Paris, but he made measurements of the quantity of fire-gas given off, and of the alterations in the weight of the body yielding it. It is to be placed to the credit of the French chemist, that he carried out a systematic inquiry into the quantities engaged in these changes. He established the constitution of atmospheric air, showing that it consisted of fire-gas and an inert gas. Lavoisier, too, was aware that certain metals became *heavier*, when heated and calcined.

It was Lavoisier who maintained, that a part of the atmosphere combined, in the act of burning, with the object burning, and that the basis of the event did not consist, as most of his learned contemporaries believed, in the escape of a fiery principle, or **phlogiston**, from the substance burnt. For long this theory of phlogiston had been accepted without question, and it was only abandoned, when Lavoisier's convincing demonstration of the transfer of matter, from the atmosphere to a combustible body, in the act of burning, was achieved by the aid of the balance. The substance leaving the air during the event was first called *oxygen* by Lavoisier.

Clearer views began to gain ground about this time as to the nature of different kinds of matter. That various substances were different, by reason of a difference in the grouping together or combination of a limited number of **elementary substances**, had always been entertained from the earliest days of Natural Philosophy; but a clear conception of the elements as a certain limited number of substances, which cannot be resolved into more simple components, is of comparatively late growth.

The elementary state is one which does not allow of further analysis. *Gold, silver, sulphur*, are elements, because they cannot be resolved into other kinds of matter. From gold, nothing but gold can be obtained, and all such bodies are elements. From calcined mercury or nitre, the early chemists showed that other

substances could be obtained, and they are, therefore, not elementary but *compound*. All the complexity, which natural objects present to us, is occasioned by different modes of combination of some seventy or more elements. And Chemistry is *the science which deals with the modes in which these combinations take place*.

It is not difficult to see, that the *quantity* of one kind of matter, entering into combination with another kind of matter, stands out as one of the chief things to be studied. The balance was the instrument which led to the establishment of modern Chemistry, and, *through the process of weighing*, its development and expansion has been sustained. Attention was early given to the characteristic ratios which mark chemical union, and with their consideration arose, almost imperceptibly, the irrepressible belief in the **indestructibility of matter**.

In much of the reasoning used in these early days, the principle, that matter cannot be destroyed or created, formed a part, though perhaps unconsciously, of the argument. We can now see clearly that this belief is a *necessary* part of our present views. Chemistry is *based upon* the accuracy of the statement, that matter is indestructible. If it be not true, that the total quantity of matter in existence is absolutely fixed and invariable, at all events within the field of our observation, then all the theories of Chemistry are wrong, and a new science will have to be constructed.

Among the many problems which Chemistry has to solve, though so far no approach to a solution has been reached, is the remarkable change in appearance, which occurs when a substance enters into combination. Why a substance should lose all the external qualities by which we recognise it, has not yet received an explanation. Why oxygen and hydrogen should lose their identity, and merge themselves in a new material, water, is not known. All their qualities do not disappear. There is one prominent fact which remains, and it must remain, if the **conservation of matter** is true. There is no alteration in *mass*. Though there is so fundamental a change, in respect to which our senses give us information, as when, for example, two impalpable

gases produce the liquid water, yet there is no change whatever in the total quantity of matter.

Lavoisier himself states emphatically, that an equal quantity of matter exists before and after the act of chemical change. The consequences of this important statement are to be found in Dalton's comprehensive theory of the existence of **atoms**, differing in weight for different substances, and entering into combination with one another in accordance with their characteristic weights. The important series of events which lead to this **Atomic Theory** of Dalton, and the course of the argument used in support of it, demand more attention than can be given to them here. But one thing, even at this stage, must be emphasised, and that is the distinction between chemical events and the effects of gravitation or momentum. *Equal quantities of different kinds of matter are not alike in chemical affairs.* There is no chemical equivalence between equal masses of mercury and oxygen. On the contrary, notably unlike quantities, called **chemical equivalents**, are those which are alike in value for chemical action.

Chemically Equivalent Quantities.—Notice the properties of hydrochloric acid solution, how it turns blue litmus solution red, its corrosive action on metals, such as zinc and iron, its action upon limestone, or carbonate of soda. Behaviour of this kind is our reason for calling it an **acid**. An exceedingly dilute solution would have a sour taste, and so have many acids, but it is unsafe to try it.

Next, observe the properties of caustic soda or sodium hydrate. It has a soapy and destructive caustic action on the skin. A small trace alone is enough to show this. It dissolves very readily in water, making the water warm in doing so. The solution obtained turns the red litmus solution blue again, apparently neutralising the action of the acid in some way. It does not resemble the behaviour of the acid in any way, and if the solution is added in sufficient quantity to the acid solution, the latter *loses all its distinctive properties*. It no longer shows the properties that induced us to call it an acid.

The alkali, soda, does *neutralise* the acid, that is to say, it counteracts its acid nature. And this fact is nothing more than what may be observed in every chemical change, an alteration in the *visible and salient properties* of the substances engaged in it.

But the question of quantity now concerns us most. Employ burettes and pipettes for the measurement of quantity. Remember that equal

volumes of a given solution contain equal quantities of the dissolved body. In a solvent, the solid is uniformly distributed.

Use equal quantities, 10 cubic centimetres for example, on each occasion, taken from the same stock of soda solution; add to them a little litmus solution, and ascertain, by making repeated trials, the exact quantity of the same acid solution, which is needed to obtain a neutral or purple colour in the solution. So long as there is any caustic soda left unacted on, the colour will remain blue. If more acid is added than is needful for neutralisation, the colour turns to red. The intermediate state, when neither too much nor too little acid had been added, is indicated by a purple colour. Some practice will be needed to hit it off.

Once the right quantity has been obtained and noted, it will be found to hold on each occasion, and to hold without any observable change under all circumstances.

A definite quantity of caustic soda always reacts with a definite quantity of hydrochloric acid. The acid property will disappear in this case, and so will the alkaline quality.

Evaporate the neutral solution, obtained by mixing the right quantities ascertained to be needed, but do not use any litmus. Observe that as dryness approaches, a white crystalline solid appears. Continue until nothing but a solid is left. This differs in appearance and property from the alkali, and it has no resemblance to the acid.

A new substance, a neutral body called a salt, has appeared. This is common table salt, also called *sodium chloride*.

Use again the same quantity of the alkali, namely, 10 cubic centimetres, and run in the quantity of another acid needed to neutralise it. Use weak sulphuric acid. The same experiments will be needed, to ascertain, with the aid of litmus, when the neutralisation is exactly reached. Observe that equal quantities are needed on each occasion, as before. A definite quantity of alkali reacts with a definite quantity of sulphuric acid.

Evaporate, and observe that a neutral white crystalline salt is obtained. It is sulphate of soda, and it may be shown to be unlike the salt previously obtained.

Weigh a small porcelain dish, and use larger quantities of the components, preparing and weighing the two salts, obtained from the reaction of equal quantities of the alkali with the quantities of the two acids needed to equalise them. The ratios previously ascertained will be observed. Different quantities of the two salts will be obtained, and as the same quantity of alkali is used in each case, it may be inferred that different quantities of the acids are engaged in the reaction.

Different quantities of different acids neutralise equal quantities of the same alkali.

The same fact may be conveyed in the statement, that *different quantities of different acids are chemically equivalent.*

Similar experiments may be carried out with the same quantity of a given acid, and the chemically equivalent quantities of different alkalis be ascertained. These too will be found to differ. Caustic soda and caustic potash may be used.

Weigh out .25 gram of magnesium wire, and the same quantity of clean bright iron wire. Fill two measuring-cylinders, holding 500 cubic centimetres, with dilute hydrochloric acid, and invert over a basin of acid. Slip the magnesium under the one, and the iron under the other. Gas will be disengaged, but to a different extent by the two metals. Experiments may be made to demonstrate, that the gas is the same in each case. It is called hydrogen.

Different quantities of the same gas are liberated from the same acid by equal quantities of different metals. It may be inferred then, that different quantities of different metals are equivalent to one another in this experiment.

Further Experiments to show that Different Quantities of Various Substances are Chemically Equivalent.—The displacement of silver by magnesium is effected. Weigh a small quantity of magnesium. Add it to silver nitrate solution in a weighed crucible, and pour off the clear liquid when the action is complete. Wash, evaporate, and weigh the silver obtained, and compare it with the weight of magnesium employed in liberating it.

Place a small quantity of bright iron wire in a warm solution of copper sulphate in a weighed vessel. Copper is set free. Pour off the liquid when the action is complete. Wash, evaporate, and weigh the copper.

In each case precautions are needed. Washing is needed to get rid of the non-significant material. Care must be taken that the action is complete. All the iron, and all the magnesium, must have entered into the solution, or what is weighed will not be wholly copper, or wholly silver, as the case may be.

Weigh a thin strip of zinc, and suspend it by a thread in a solution of lead acetate. Collect and wash the crystalline lead which is deposited, when the action is complete. The lead may be dried and weighed. The quantities of zinc and lead should be found to be in the ratio of 65 to 207.

It is no uncommon experience to find, that special changes attract our attention more persistently than those which are more general. And this inquisitiveness over exceptional events is not

to be wondered at, when we remember how readily we accept without inquiry that which is frequent and general. Chemical, thermal, and electrical changes arouse curiosity at once by their novelty, but the effects due to gravitation are so familiar that they are taken for granted, and so general that they frequently pass without recognition. The movement of bodies towards the surface of the earth, after being displaced therefrom, and the limitations which are fixed to all attempts to move bodies from the earth's surface, are familiar instances of a constant, general, and uniform relation of all parts of the earth to the earth as a whole.

The burning of coal, gas, or candle are remarkable events which have always attracted attention, and been the subject of much speculation, though they have been incorrectly explained until within comparatively recent years. The reflection of light again is taken for granted. It is familiarised by the use of mirrors. But an analogous occurrence, refraction, at once attracts the attention.

When once it is recognised, that the stress of the earth is constant and unavoidable, and when it has become possible to measure its value in any given case, the existence of the stress may be turned to good account. Other stresses, by comparison with that of the earth, may be measured and expressed in terms which are readily understood. Without the aid of this universal stress for purposes of comparison, we should be at a loss to estimate much of what we observe. To understand the service rendered by gravitation as a means of comparison, attention must be given to a striking feature in it, which appears in none of the other stresses hitherto investigated. The value of the stress never varies with the nature of the substance. It is conditional on the *quantity*, but never on the *quality* of the matter concerned. On the other hand, the stress which is called chemical action, to take an example, is remarkably *discriminating* and *selective* in its operation. Chemical changes never take place, except between certain definite quantities of the reacting material, and certain kinds of matter are alone capable of reacting chemically. The Science of Chemistry is mainly concerned with a classification of different kinds of matter in accordance with their reactions, and with the determination of the relative quantities engaged in these reactions.

Thermal Changes in Relation to Quantity of Matter.—It is scarcely necessary to demonstrate, that the resultant temperature, when two quantities of water at different temperatures are mixed, is somewhere between the two. It is an invariable experience, that when bodies of different temperature are brought together, they assume in course of time the same temperature.

Use two equal quantities of water at different temperatures. One quantity is to be placed in a large beaker packed round with cotton-wool or asbestos. Its temperature may be for convenience that of the room. Pour into it the equal quantity of water, which is warmer, and has its temperature taken just before it is poured. The resultant temperature, after stirring with the thermometer, will be found midway, or nearly so, between the two. The one has gained, and the other has lost, the same quantity of heat, except so far as the vessel and surrounding air have gained in temperature.

The unit of heat, or **calorie**, is that quantity which changes the unit quantity of water (or 1 gram) through 1° C. This is the metric unit. The English unit would be that which changes 1 lb. of water through 1° Fahrenheit.

With this idea of heat as a quantity before us, it is easy to see how changes of temperature have a very different value, according as the quantity of matter undergoing it is great or small. In this we have a resemblance to momentum. A small change of temperature in a large mass is like a small movement in a large mass. A small change of temperature may be an event of great magnitude, if it takes place over a large mass.

To realise this more vividly, raise a piece of platinum wire by means of a blowpipe to a white-hot state. A very high temperature, higher than can be measured directly, is reached in the platinum. Allow it to fall immediately into some water in a beaker. Note that the change of temperature in the water is inappreciable.

Thermal Changes in Relation to Quality of Matter.—Mix together equal masses of water and turpentine at known temperatures, in the manner already described. The resultant temperature after stirring well is not midway. Perform the same experiment, using water and mercury. Pour the warmer mercury into the water placed in a beaker packed in asbestos wool.

The same fall of temperature in two different substances is not the same physical event, and this is why the change of

temperature in one direction, in the one kind of matter, is not balanced by a similar change in the contrary direction, in a different kind of matter. A fall of 10° , for example, in water does not correspond with a rise of 10° in turpentine or mercury.

Similar changes of temperature do not balance one another, or correspond with one another, in different kinds of matter.

All thermal changes are influenced by the substances with which they are associated. When equal quantities of the same kind of matter at different temperatures are instantly mixed, the resultant temperature is midway between the original temperatures. But if equal quantities of unlike substances are brought together under similar circumstances, the resultant temperature is not the mean, but varies according to the nature of the substances used. This gives rise to the rather clumsy term **Specific Heat**, which denotes that the value or magnitude of the thermal effect depends upon the species of matter as well as the quantity.

In rough experiments, approximation to the truth is the most that the student must expect. Unless a long period of time be given up, and many refinements of precaution adopted, in carrying out the investigations, the best results cannot be obtained. Accurate values can never be obtained, unless our observation *include everything which undergoes change*. In these crude experiments a number of changes are purposely ignored.

Quantities which are Thermally Equivalent.—If the cooling of one kind of matter through 1° be not equivalent to the rise of another through 1° , when they are in intimate contact, it should not be difficult to ascertain, in what quantities the bodies must be present, in order that similar changes of temperature in them may be equivalent, or in other words, how much of each is wanted in mutual exchanges of heat.

Weigh out about 20 grams of copper foil. Roll it into a coil. Suspend it so that it will hang evenly in, and be well covered by, about 200 grams of water in a beaker. This water is prepared, and its temperature taken. Meanwhile heat the copper coil to a known temperature, and immerse it in the water, without touching the sides of the vessel. The heating may be done by immersing the copper in boiling water for a few minutes. It is true, that water will cling to it as it is being transferred to the beaker, but the error due to this is very slight compared with any inaccuracy in the

reading of the thermometer. Unless the transference is very rapid, the temperature of the copper will not be much over 90° when it reaches the beaker. Move it about by twisting the thread, to allow of exchange of heat with the water. Take the temperature of the water.

It is necessary to calculate from your observations, what quantity of copper, changing through 1° , would be equivalent to 1 gram of water, changing through 1° . This is not difficult to carry out. But, first of all, we may restate the basis of all such thermal measurements.

A change of 1° C. in 1 gram of water is the unit quantity of heat. Similar alterations of temperature, within the limits of our experimental work, may be taken as of equal value. For example, a change from 50° to 51° may be accepted as equal to that from 10° to 11° . They are not strictly alike, though very nearly so, but we must for the present regard them as alike.

The product of the number of grams of water affected and the number of degrees of change gives the number of units of heat. 100 grams of water changed through $1\frac{1}{2}^{\circ}$ requires 150 units of heat, or as we may say, 150 units of heat are absorbed in changing 100 grams through $1\frac{1}{2}^{\circ}$. To change 50 grams through 3° would absorb the same quantity of heat, and the fall of 50 grams through 3° would provide enough heat to raise 50 grams by 3° . And, a fall of temperature in one body taking place while another body becomes warmer, these changes are mutual and self-explanatory.

But if we are dealing with a substance which is not water, we must bring it into comparison with water. It is clear that a change of 1° in copper is not equivalent to a change of 1° in water. We may ask two questions:—

1. How much copper is equivalent to 1 gram of water in a thermal change? Or,

2. How far will a gram of water be raised in temperature by 1 gram of copper in falling through 1° ?

Both questions refer to the *same physical fact*, and this fact may be expressed in different ways. Either we may say, as the result of investigation, that 10.52 grams of copper are equivalent to 1 gram of water, and that a given change in this quantity of copper corresponds with the same change in 1 gram of water; or, on the other hand, we may say that 1 gram of copper in changing

through 1° C. corresponds with a change of .095° in 1 gram of water. The fact is the same. The form of expression is a matter of choice.

10.52 grams of copper are equivalent to 1 gram of water, or
1° in 1 gram copper corresponds with .095° in 1 gram water.

$$\frac{1}{10.52} = .095 \text{ approximately.}$$

Now there is still another way of looking at this same fact. Inasmuch as the change of 1° in 1 gram of water is regarded as the unit quantity of heat, we may take the change of a fraction of a degree in 1 gram of water as a fraction of a unit of heat. Therefore we may say that .095 of a unit of heat will be needed to raise 1 gram of copper through 1°. A term which is a relic of the past embodies this idea, namely, **specific heat**, and it is usually defined as the quantity of heat required to raise the temperature of 1 gram of the substance through 1° C. It is a quantity which must be represented by a *fraction*, for the capacity of water for heat is greater than that of most bodies, and the specific heat of water is taken as 1.

When the unequal capacity of different kinds of matter for heat is represented by a table of the quantities of various kinds of matter, which are equivalent in thermal respects to 1 gram of water, we bring our result into line with similar series of equivalent quantities. **Thermal equivalents** may be compared with **chemical equivalents**, and in many cases similar ratios occur. For example, we know that 10.52 grams of copper and 8.92 of iron are equivalent to 1 gram of water in the matter of thermal change. But nearly the same ratio is preserved by copper and iron in chemical exchanges. A few other values are now given:—

TABLE OF THERMAL EQUIVALENTS.

Air	4214.7	Lead	31.74
Aluminium	4.95	Mercury	31.32
Brass	10.64	Platinum	30.86
Benzine	2.2	Silver	17.89
Copper	10.52	Tin	17.89
Glass	5.0	Water	1
Gold	30.86	Zinc	10.69
Ice	2.0	Iron	8.92

On comparing these numbers with those which represent equivalence of other kinds, we shall find reason in the relation, to regard changes of temperature as events touching the particles, of which visible portions of matter are composed. It is *not the volume or the mass of matter*, which puts conditions upon thermal events. It is clearly something more intimate which is under change, and, we may argue, it is the indistinguishable constituent parts of matter.

The results of chemical and of electric researches make this statement probable. That there are certain physical events, which touch the inner particles rather than the visible matter, is to be inferred from chemical, electric, and thermal observations with equal certainty. Chemical, thermal, and electric equivalents point with considerable agreement in the same direction.

Further Practical Work in Calorimetry.—The thermal equivalents of several substances should be measured, noting—that the best results will accrue if the material exposes as large as possible surface to the water—that no losses of heat should be overlooked—that as large as possible change of temperature in the substance is advisable—and that great error in the calculations may result, from a slight error in the reading of the temperature of the water, for a mistake of $\frac{1}{8}$ th of a degree is serious when it is multiplied by 200 or more.

Shot, granulated zinc, aluminium foil, and small iron nails, in known quantities, may be used. To raise their temperature, they may be placed in a large tube, and the tube immersed in boiling water. A thermometer in contact with the substance will indicate the temperature approximately. Care is needed to prevent the breaking of the glass vessels. It is always well to support the calorimetric vessel by threads, to prevent loss of heat by conduction, but it must not be forgotten, that loss by radiation is always going on in these experiments.

As in the previous experiment, the temperature of a known quantity of water rises, until there is thermal equilibrium between it and the objects placed in it. But the resultant temperature shows, as we may expect, that the change in one substance is not equal to the change in the other, even when their relative quantities are taken into account.

To realise still more clearly, that different quantities of unlike substances are thermally equivalent, prepare two beakers, each with about 200 grams (or cubic centimetres) of water in it, at the same temperature as the room. Suspend by a thread a piece of aluminium foil weighing 4.95 grams, and a piece of sheet-lead of about the same thickness weighing 31.74 grams. Hang them in boiling water for a few minutes, then place the lead in one beaker and the aluminium in the other. It is better to allow them to hang in the water, if possible, without touching the bottom. Notice that after a few minutes, when equilibrium is obtained, the temperature of the water is the same in each case.

Here the same effects have been produced, under precisely the same conditions, by two very different quantities of the two unlike substances.

The Melting of Ice.—A known quantity of water at a known temperature has a small piece of ice placed in it. When it is melted, the temperature of the water is taken, and the whole again weighed. The addition to the mass represents the ice added.

It is known that the water, which is obtained from the liquefaction of ice, is the same temperature as the ice before it melted. Place a thermometer in a vessel full of crushed ice, and this will be clearly seen. The temperature remains at 0° , so long as there is ice unmelted.

But an important question arises. What events are in progress to account for the change from the solid to the liquid state? The answer will be found by measuring the changes that take place in the water, air, or other material, which surrounds the ice while it melts. They are found to cool remarkably. While a small quantity of ice is changing its state, a large amount of energy in the form of heat leaves the objects near it. It is convenient to allow the ice to be surrounded by water for purposes of measurement, but any other body in the place of the water would be correspondingly lowered in temperature.

If 10 grams of ice be added to 200 grams of water at 14.5° , it will be found, that the temperature of the whole, after a time, is about 10° . From this fact it is clear, that while 10 grams of ice have melted, and while the water resulting from it has risen to 10° , the whole of the 200 grams of water have fallen through $4\frac{1}{2}^{\circ}$. That is, 900 units of heat ($200 \times 4\frac{1}{2}$) have been absorbed, in melting 10 grams of ice and raising the result to 10° . Or, 10 grams ice melt and rise to 10° , while 200 grams water fall $4\frac{1}{2}^{\circ}$, or, again,

900 units are used in melting 10 grams of ice, and in supplying 100 units ($10 \times 10^\circ$).

900 units cause change of state and supply 100 units,
900 - 100 units are therefore used in melting 10 grams ice, or,
80 units used in melting 1 gram ice.

Results approximating to this value should be obtained. The number of units of heat required is called the **latent heat of water**. It is the heat absorbed in performing the work of melting the solid. A certain quantity of energy is always absorbed in the performance of work. The nature of the work is not apparent. It is inferred to be a disturbance in the grouping and position of the minute particles constituting ice and all other matter. The liquefaction of all solids requires a supply of energy. The exact amount varies with the kind of matter being liquefied.

Note.—It should be remembered that once water is frozen the temperature may fall continuously. While freezing, or while melting, there is no change in temperature, and the same remark applies to all substances.

Heat absorbed in melting Paraffin.—A determination of the same character as the last may be carried out with paraffin-wax. The solid paraffin is placed in a weighed beaker, and its mass ascertained. A known quantity of warm water at a known temperature is added, and the temperature taken after the liquefaction of the paraffin.

To ensure greater accuracy in this experiment, it is advisable to ascertain the cooling, which would take place in hot water when placed in the beaker for three minutes. This cooling is due partly to radiation, and partly to the warming of the beaker and of the air near at hand. The number of units of heat lost in this way, in the time occupied by the experiment, may be found out, and allowance may be made for them in the calculation. In order to render the melting of the paraffin as rapid as possible when the observation is made, it is advisable to spread it in a thin layer over the bottom of the vessel. This may be done by melting and allowing to cool. For the glass beaker a nickel vessel may be substituted, but in any case a preliminary observation must be made, as to the cooling which would take place if the paraffin were not present.

The heat absorbed, in raising the temperature of the vessel itself, is estimated in terms of what is called its **water-equivalent**. That is, observations are made, and these are

simple enough, to find out the quantity of water to which the vessel is equivalent. It is often desirable to be able to regard the vessel as so much extra water.

The measurement of heat is usually taken from the change in a given quantity of water in a vessel. But the vessel itself changes somewhat. How much it changes, or rather what number of units of heat have to be allowed for this change, is ascertained, by adding a known quantity of water at known temperature, not too high, and observing its fall. If 10 grams of water fall in this process from 17° to 16° while the temperature of the room, and therefore of the vessel at first, is 15° , then the temperature of the vessel may be considered to rise through 1° (from 15° to 16°), and 10 units of heat are required to bring about this change (10 grams of water falling 1°). Now we know, that had the 10 grams of water at 17° been placed in 10 grams of water at 15° , it would have raised it to 16° , just as much as it has raised the vessel. Therefore, we regard the vessel as *equivalent to 10 grams of water*.

The Conversion of Water to Steam.—An absorption of heat, similar to that just witnessed in the melting of ice, takes place when water passes to steam. Now as this event is a change of state still more remarkable, for it must be admitted, that steam is still farther removed from water in all its properties, than water is from ice, we may expect it to be accompanied by *more striking thermal changes*, than those which take place when ice melts. Just as ice does not change in temperature while it is melting, so water in boiling never alters. It remains at 100° .

Now it must be stated before we begin, that when water changes to ice, a quantity of heat or energy is set free, corresponding to that absorbed in the converse change. To melt ice, heat is said to be rendered *latent*. Hence the term "**latent heat**" is used, though nothing, strictly speaking, is latent, and the changed condition explains the absorption of heat. But in the freezing or solidifying of water, the converse change occurs. Surrounding bodies are warmed, in the same degree as they are cooled on melting.

In just the same fashion, the heat absorbed in vaporising water is restored to the bodies near it, when steam liquefies.

Surrounding bodies gain a large amount of heat during this change, just as much as the steam took up during its formation. Assuming this statement to be true, and there are numerous facts to support it, we may measure the latent heat of steam, by observing the changes which occur when steam is condensed to water. This happens to be by far the most convenient method of making this measurement.

It is necessary to pass *dry* steam into a known quantity of water at a known temperature. It is important to have the steam dry, that is, in the

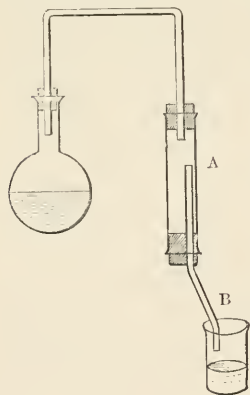


FIG. 26.—Apparatus for determining the latent heat of steam.

state of a gas before it has begun to condense, otherwise some of the heat evolved will escape our observation. To prevent any loss from premature condensation, the steam from a vessel of boiling water passes through a tube leading into a wider tube, *A*, Fig. 26, from which it emerges by a narrower tube, *B*, and then may pass directly into the weighed quantity of water. Condensed steam will collect in the lower part of *A*, but the opening of tube *B* remains above this. As soon as steam has been allowed to escape long enough to warm the apparatus, it will be evident that the steam escaping from *B* is wholly in the gaseous state. It is then allowed to pass into the water, until the water becomes moderately hot (not above 50°). Remove the tube, with as little water as possible adhering to it, and read the temperature. Weigh the vessel again, and note the increase in weight. The increase repre-

sents the matter which has changed its state.

The estimate of the steam condensed in the water is the most probable source of error in the experiment, and, for this reason, it is important not to take away a quantity of water from the calorimeter in removing the delivery-tube, and it is important, also, not to allow so much steam to be condensed, that the water loses by rapid evaporation. Unfortunately, both these losses are on the same side, that is, they make it appear, that less than the actual quantity of steam has been added. Against this error, there is considerable loss by the *cooling of the water* during the

experiment. This may be ascertained by noting the time of the experiment, and then finding out the extent of cooling which takes place in that time, under any circumstances, with water of the mean temperature obtaining during the experiment.

In careful work it would be important to prevent cooling, as far as possible, by careful insulation of the calorimeter. In a rough experiment of this kind, the heat from the flame used in boiling the water in the flask would help to compensate for the loss by cooling in the calorimeter.

The numerical value, for the conversion of 1 gram of water to steam (or of 1 gram of steam to water, which has the same value), is gained, by taking into account, (1) that a given quantity of water is raised through a known number of degrees, and (2) that this is done by a known quantity of steam changing to water at 100° (the temperature of steam itself), *and then falling from 100° to the temperature of the rest of the water.* In other words, the number of units of heat given out by steam in condensing is equal to the number gained by the water, *less that number contributed by the condensed steam in falling from 100° to the final temperature.*

All these values are to be practically ascertained, and the calculation for 1 gram is very simple, if the results of the experiments are entered in a notebook as follows:—

Mass of water used	.	.	.	.	.	.	.	.
Temperature of water at start	.	.	.	.	.	.	.	.
„ „ at end	.	.	.	.	.	.	.	.
Increase in mass of water (or steam engaged)	.	.	.	.	.	.	.	.
Observed latent heat of steam (or heat evolved when 1 gram of steam condenses)	.	.	.	.	.	.	.	.

Every liquid absorbs a certain quantity of heat, varying with the nature of the liquid, on being converted into a vapour; and on passing back to the liquid state, the same quantity of heat is evolved.

It is not always easy to comprehend, that water at 0° must give out energy as it freezes, in spite of the very obvious results which ensue, when steam at 100° condenses to water at 100° . The main requirement, for success in observing this condition for

change of state, is to be able to hasten the change. If the freezing of water were to take place *suddenly*, it would be more apparent. As it is, the change takes some time, and the effect is not evident. To attempt to understand the facts better, ascertain the latent heat of paraffin-wax.

Draw up a little liquid wax in a narrow piece of glass tubing, close up the end, allow it to cool, and fasten to a thermometer. Place them together in water, gradually raise the temperature of the water, and watch when the paraffin melts. Several observations will enable a mean temperature to be taken, and this will be more likely to be accurate.

Then, having found the melting point, prepare a small quantity of water at this temperature, and also a quantity of liquid paraffin-wax. Pour a quantity of the liquid wax into the water, and a distinct rise of temperature will be observed, although the liquid poured in was at the same temperature as the water.

By weighing the water before and after the paraffin is added, and noting the change of temperature produced by the solidification of the paraffin, an approximate value for its latent heat of fusion may be obtained.

Quantity of Matter and Electricity.—In many of its manifestations, there is no distinctive connection between quantity of matter and electrification. In the passage of electricity through solid bodies by the process of conduction, there is no indication of *quantity of matter* being a consideration. The *dimensions* of the conductor do influence the process of conduction, and it is true that quantity is connected with size. Along a thick conductor conduction takes place more readily than along a thin one. *Sectional area is the significant quantity*, and, as is known, the process varies also in accordance with the kind of matter.

Again, the quantity of matter in a conductor does not determine the change produced in it by a charge of electricity, but the *extent of its surface* is all-important. When two bodies of different temperature are brought together, resultant temperature depends upon their relative quantity and their kind. But when two bodies in a different electrical condition are brought together, their resultant state with regard to electricity, when equilibrium is attained, does not depend upon the kind of matter, nor upon its quantity. It depends upon the surface which the body presents. A hollow body behaves in the same fashion, with regard to an

electric change, as a solid one of the same size and shape. Their electric **capacities** are alike.

But when a current of electricity is caused to pass through a conducting solution, changes may be observed in which a distinct relation to quantity and kind of matter asserts itself. A process of **electrolysis** usually occurs, when a chemically complex liquid conducts electricity, and values known as **electro-chemical equivalents** are as characteristic in these changes, as chemical and thermal equivalents are in their special changes.

Weigh and mark two clean and bright copper plates, and connect them with a support, such as shown in Fig. 27. Place them in a solution of copper sulphate in a beaker. Weigh also carefully, and mark, two small bright silver plates, and connect them in the same manner with a support. Immerse these in a solution of silver nitrate in a beaker. Connect these plates immersed in the

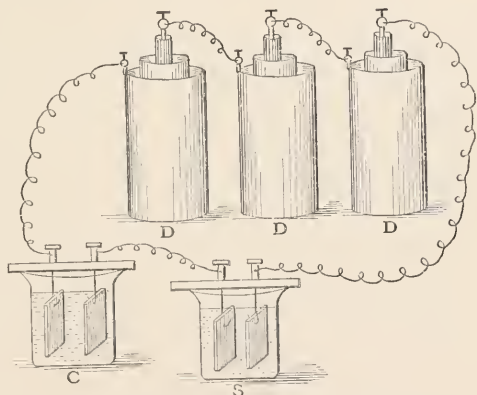


FIG. 27.—Apparatus for experiments on electrolysis.

D = Daniell cells.

C = Copper voltameter.

S = Silver voltameter.

liquids, and serving the purpose of **voltameters**, or current measurers, with two or three Daniell or bichromate cells. That is, introduce them into a circuit through which a current may pass, and connect them in such a manner that the voltameters form successive parts of the circuit. In that case, the *same current* will pass through both vessels. Allow the current to pass for about ten minutes. Dry and weigh again the plates on which a deposit has occurred. Reference to the marks will enable you to distinguish the plates, and the difference between the present and the original weight informs you of the quantity of matter deposited (in the one case it is copper, in the other silver). *The amount of deposit of a known material is the standard by which quantity of current is measured.*

It will be noticed, that the quantities of the two kinds of

matter, deposited under identical circumstances, are different. The relative quantities of silver and copper deposited will be in the ratio of the *electro-chemical equivalents*. All these equivalents are determined by experiments of this kind. *They will be found closely connected with chemical equivalents*. This means that the special quantities, between which chemical action takes place, are the same as those which are liberated under the action of an electric current.

It may be noted in connection with this change, that all points of a circuit are alike with regard to electrolytic energy. There may be alterations in the physical conditions at certain points, the conducting material may be changed in dimensions or kind, but the same current value for the electricity obtains everywhere, as is evidenced by the fact that *the chemical changes correspond, however much these conditions may vary*.

And it may be pointed out that the chemical changes within the cell are included in this statement. *The substances within the cell undergo changes similar to those without*.

Summary.—Wherever events of a physical or chemical nature, excepting only those in which the ether itself is mainly engaged, *e.g.* light and certain electric events, are proceeding, there is always a certain quantity of matter engaged. This fact may not appear directly or prominently. But we have already learnt that every change in nature is preceded or accompanied by another change, and this by still another, and so on. We may now, however, make a still more definite statement, that the immediate and direct cause of every physical change, with the exceptions above stated, is another physical change, *involving a certain quantity of matter*, and the quantity involved is always a measure of the extent of the change produced. In the illustrations which have preceded, it will be evident, that whether we are dealing with heat, electric current, or mechanical work, there is always, somewhere or other, a certain equivalent transformation, or, as it is more usually termed, consumption of energy, going on, at the same time, and corresponding with it.

QUESTIONS AND SUGGESTIONS FOR PRACTICAL WORK.

Note.—In the measurement of heat, or *calorimetry*, the following terms are used:—

Calorie, the quantity of heat required to raise a gram of water through 1°C .

Specific Heat, or specific capacity for heat, a number denoting the quantity of heat required to raise a gram of a substance through 1°C .

1. Take equal weights of copper, iron, and aluminium (wire is most suitable, as equal weights are most easily obtained in this way), place them in boiling tubes, heat them to 100°C . and plunge each into equal quantities of water at same temperature. Note carefully what happens in each case, and suggest deductions that may be formed from this experiment. What difference would it have made if equal volumes had been used?

2. Calculate the number of calories needed to raise 100 grams of water from 0° to 15°C ., and also to raise the same quantity to 60°C . Mix two such quantities of water together thoroughly and take the temperature of the mixture. Explain clearly what has become of the heat lost in the one case and gained in the other.

3. Heat 200 grams of water to boiling point, and allow it to cool, taking its temperature at the end of each minute. Write down carefully the number of calories it loses at each observation, and also the number of degrees.

4. Explain clearly what is meant by saying, that the specific heat of water is thirty times as great as that of mercury.

Mix a kilogram of boiling water with a kilogram of mercury at 0°C . and ascertain the temperature of the mixture. Explain what has happened.

5. What distinction, if any, exists between “specific heat” and “thermal capacity.” Find the heat-capacity of a calorimeter; that is, how many calories will raise it 1° .

6. How much steam at 100° will exactly melt 10 kilograms of ice?

7. Find out, (1) by method of mixture, (2) by method of fusion of ice, (3) by method of cooling, the specific heat of a known quantity of buck-shot.

Account for any difference that may occur in the results obtained.

8. Describe any form of calorimeter, and the method of using it.

9. Distinguish carefully between “degree of temperature” and “unit of heat.” 20 grams of steam at 100°C . are condensed in a metal tube surrounded by 200 grams of water at 10°C . If the water equivalent of the tube be 10 grams, and the latent heat of steam 536, calculate the temperature to which the water will be raised.

10. How would you compare the thermal conductivities of bodies whose capacities for heat are different?

11. The specific heat of copper is $\cdot 09$. How many lbs. of copper at 300° C. will produce 2 lb. of water when placed in the ice calorimeter?

12. A piece of tin weighing 125 oz. is kept in boiling water till its temperature is 100° . It is then taken out and dropped into 63 oz. of water at 0° C. The temperature of the water then rises to 10° . What is the specific heat of tin?

13. A piece of iron, weighing 750 grams, at 200° C. is placed in ice at 0° C. How much ice will be melted? Specific heat of iron = $\cdot 114$.

14. You are given a piece of brass, weighing 50 grams and at a temperature of 16° C., how many calories will be required to raise it to a temperature of 26° C.? (Brass has a specific heat of $\cdot 09$.)

15. What temperature is denoted by the same number in the Centigrade as in the Fahrenheit scale? Is there more than one temperature which fulfils this condition?

16. On the summit of a mountain water boils at 182° F.: if a thermometer were graduated there, without taking into account the atmospheric pressure, what would be the real temperature when this thermometer registers 62° F.?

17. Take several short bars (thick wire) of different metals, heat them at one end in the same way. Take the time required in each case to reach the same temperature at the other end. How does this agree with the order of their several conductivities for heat? Explain any difference that may appear.

18. Make a supersaturated solution of sodium sulphate. Describe and explain the rise of temperature that occurs, when a crystal of the same salt is dropped into such a solution.

CHAPTER VIII

PHYSICAL AND CHEMICAL PROPERTIES OF MATTER

Matter is formed of Small Particles.—Although our knowledge of the ultimate composition of bodies is at present of a somewhat limited nature, still there are many facts which lead us to suppose that solids, liquids, and gases, each and all of them, are really made up of *very minute particles of matter*.

Different substances have *different kinds of particles*, but in every case these particles are too small to be visible with even the most powerful optical instruments. If we take any elementary substances such as sulphur and lead, which are solids at the ordinary temperature of the air, and warm them in a vessel, in each case we get the same result, viz., that the solids gradually lose their shape and become liquid. This can, on reflection, only be accounted for in one way. The small particles of the solid on being heated increase their **vibratory motion**, and are thus unable to remain in the same positions relative to one another, as they do when the temperature is low and excursions are more limited.

We have good reasons for believing that even in the hardest of solids *the particles do actually vibrate*, but the movement is so small, that the solid retains its definite shape, and the position of one particle as regards its neighbours is unchanged. When we heat even such hard substances as iron, however, a change sets in, and the particles take up new positions, and begin to roll over each other, and eventually the solid is converted into a liquid. The more we raise the temperature the *more mobile* does the liquid become, and if we continue long enough, or are able to apply sufficient heat for the purpose, the particles now begin to

move about so freely, that they escape in increasing numbers from the surface of the liquid, and, in time, the liquid becomes entirely changed to a gas, which rapidly diffuses and spreads all over the room, however big it may be.

Almost every elementary substance has been obtained in each state of matter, either as solid, liquid, or gas. Even refractory substances such as hydrogen gas have by means of pressure, and cold, been reduced first to the liquid, and then the solid state.

Experiments.—1. Take a small flask of alcohol and place it in a large cylinder. Then carefully add water until it is above the mouth of the flask. It will be found that after some little time the alcohol has diffused out from the flask and has permeated throughout the water, and that the water has in like manner invaded the flask which contained originally nothing but alcohol.

This change can only have taken place by the imperceptible movement of very minute particles of each liquid.

2. In a similar way show that a solid surface such as a lump of sugar, a piece of salt, or a large crystal of copper sulphate when placed in liquid gradually disappears. The particles of the solid creep into the spaces between the particles of the liquid, and diffuse so thoroughly that it is easy to prove that after a time the whole is homogeneous. Note (1) that there is a limit to the amount of solid which can thus diffuse; (2) that the rate of solution depends on the extent of areas in contact, *i.e.* a powder dissolves more readily than a lump; (3) that movement quickens solution; (4) that temperature alters amount of solid which dissolves; (5) that the quantity of solid which will dissolve in a liquid varies with the nature of the solid.

3. To show that gases diffuse in the same way as liquids, connect two flasks one above the other, by an indiarubber tube provided with a clip. The upper may be filled with a light gas, such as ammonia, and the lower with one of greater density, such as air. When the clips are opened, the minute particles of each gas begin to move upwards in the case of one, and downwards in the case of the other, until the whole matter is homogeneous. The particles of one gas have thoroughly mixed with the other. This may readily be proved by immersing each flask in water (mouth downwards). The water will rise half-way, showing that each flask now contains half its volume of soluble ammonia gas. This experiment also shows that the particles of a gas can enter into, and permeate, a liquid just as solids do.

4. Clamp a Boyle's tube firmly in an upright position. Now pour mercury down the open arm: you will notice that the more mercury you add, the smaller becomes the volume of contained air owing to the pressure of the column of mercury. The particles of a gas can be concentrated and made to fit closer to each other by pressure. In fact, by a modification of

this experiment, compression can be carried to such an extent, that the gas will become liquid.

5. That a gas can also enlarge its volume may be seen, either by pouring away some of the mercury, when the gas will gradually resume its original volume, or by warming the gas in the closed tube with a spirit lamp, which will also bring about separation of its particles.

The volume of a gas then, we learn from this, is dependent upon two things, *temperature* and *pressure*. These two factors are indeed of supreme importance in determining the physical state of any form of matter. Whether a substance is at any given moment solid, liquid, or gas depends wholly upon the temperature and pressure.

Addition of energy in the form of rise of temperature will always tend to make the small particles of matter vibrate faster, and on the contrary loss of energy in the shape of fall of temperature will always tend to moderate the vibration, and to cause solidification.

The theory of Avogadro is founded upon observations such as the above. It is an attempt to explain the fact that *all gases undergo similar changes in volume when similarly changed in temperature and pressure*. It assumes that equal volumes of gases contain an equal number of particles or molecules, if under the same conditions of temperature and pressure, and suggests this similarity of constitution as an explanation of similarity of behaviour.

INDESTRUCTIBILITY OF MATTER.

It has already been noticed with regard to matter that, try as we may, we cannot destroy any part of it. We are enabled, by supplying to matter, various forms of energy, such as heat, electricity, motion, etc., to *change its state*, but never are we able to effect its actual destruction.

A few simple experiments will serve to emphasise this important statement.

1. Boil water in a flask connected by a tube with a receiver, the water will disappear from the flask, but reappear again in the receiver.

2. Heat some mercury in a long dry tube. The liquid will gradually disappear from the heated end and reform as small globules in the cooler end.

3. Pass an electric current through some hydrochloric acid in a two-tubed voltameter, the acid will decrease in bulk, but we shall obtain in the tubes its constituent gases.

4. A strong current of electricity passed through fragments of diamond, charcoal, or graphite in an atmosphere of oxygen causes the disappearance of the element, and formation of carbonic acid gas, from which, however, the carbon can be recovered again by subtracting the oxygen by means of heated sodium.

5. The familiar experiment of collecting (in caustic soda) the gases from a burning candle is another excellent proof.

ELEMENTS OR SIMPLE SUBSTANCES.

There is good reason to believe that matter is made up of small particles. But in some of its forms it contains *small particles of a similar nature*, that is, they are **simple bodies**; while others contain *particles of different kinds*, and these are bodies of **compound nature**.

We cannot get anything out of sulphur, by heating, except sulphur. It is still sulphur, whether in the solid, liquid, or gaseous state. Now let us dissolve it in carbon disulphide, one of the few liquids in which it will dissolve. On allowing the liquid to evaporate, we still find that we get sulphur. Sulphur belongs to a class of bodies, the minute particles of which are all of a similar character and behave in a similar way. These bodies we term *elements or simple substances*, because we cannot extract or take away from them any different kind of matter.

There are many substances of this kind, which as far as we know are **elements**: but as our knowledge is, after all, only of a rudimentary nature, it is possible that some of the bodies we consider to be elements may not be so in reality. New elements are still being found as means of investigation improve, and perhaps some day the true relationship, which undoubtedly exists, between the particles of one element and the particles of another entirely different element, will come to light. So small, however, are the particles, that it is extremely difficult to understand the changes which they undergo. The following is a list of the more common elementary bodies:—

TABLE OF COMMONER ELEMENTS, WITH THEIR SYMBOLS
AND ATOMIC WEIGHTS.

Element.	Symbol.	Atomic Weight.
Aluminium	Al	27·3
Antimony	Sb	120
Arsenic	As	75·2
Barium	Ba	137
Bismuth	Bi	210
Boron	B	11
Bromine	Br	80
Cadmium	Cd	112
Calcium	Ca	40
Carbon	C	12
Chlorine	Cl	35·5
Chromium	Cr	52
Cobalt	Co	58·7
Copper	Cu	63·5
Fluorine	F	19
Gold	Au	197
Hydrogen	H	1
Iodine	I	127
Iridium	Ir	198
Iron	Fe	56
Lead	Pb	207
Lithium	Li	7
Magnesium	Mg	24
Manganese	Mn	55
Mercury	Hg	200
Nickel	Ni	58·7
Nitrogen	N	14
Oxygen	O	16
Phosphorus	P	31
Platinum	Pt	197·5
Potassium	K	39·1
Selenium	Se	79·5
Silver	Ag	108
Silicon	Si	28
Sodium	Na	23
Strontium	Sr	87·5
Sulphur	S	32
Tellurium	Te	128
Thallium	Tl	203·5
Tin	Sn	118
Titanium	Ti	50
Tungsten	W	184
Uranium	U	120
Vanadium	V	51·3
Zinc	Zn	65·2

The vast majority of substances, which we come across in daily life, are not, however, *elements*; they are made up of two or more elements combined together and forming *compounds*. When these compounds are mixed together, as they are in bodies such as wood, we get very *complex substances*, the analysis of which becomes more and more difficult. A few simple experiments with complex bodies will show us best, how they are generally treated with a view to showing their composition, and investigating their properties.

SOLUTION AND FILTRATION.

One of the first processes which we use for separating complex bodies is *solution* followed by *filtration*.

Make up mixtures of (*a*) salt and chalk, (*b*) sugar and sand, (*c*) sal-ammoniae and finely powdered charcoal. Stir up each mixture well in a separate beaker of water. In each case one of the compounds, which forms the mixture, will dissolve in the water, and is said to be **soluble**. On pouring through filter papers, the **insoluble** body, which has not dissolved, remains as a **residue**, while the soluble one passes through in the **filtrate**.

By carefully weighing the mixture beforehand, evaporating down the filtrate, and weighing the dissolved portion, we are enabled to find out the exact proportion of soluble and insoluble salt present in the mixture. Water is the most universal solvent, but, if a substance is insoluble in water, and we wish to obtain a solution of it, there are many other liquids, such as alcohol, ether, carbon disulphide, and turpentine, possessing solvent properties which we may use.

Examples :—Iodine in alcohol.

Bromine in ether.

Sulphur in carbon disulphide.

Gold in mercury.

Fat in ether.

Heat is very often a useful agent for the separation of complex substances. Examples :—

1. Heat a mixture of sand and sal-ammoniae. The sal-ammoniae separates out from the sand in the form of vapour, and collects as a white powder at the cool end of the test-tube. This is called **sublimation**.

2. Heat some oxide of mercury in a tube. Mercury deposits as small beads at the cooler end of the tube, and, if we examine the gas in the tube, we find that it now possesses the property of rekindling a glowing taper. This gas is oxygen. We have split up or *analysed* the mercury oxide and brought about its *decomposition*.

In a similar way, try the effect of heat on copper nitrate, chalk, oxide of lead, etc., and note in each case the splitting up of the compound into more simple substances. These are all examples of *decomposition*, and the term **analysis** means the splitting up of a body into the elements of which it is composed. **Synthesis**, on the contrary, is the building up of a compound body from the elements of which it is composed. This may be easily exemplified by the following experiments:—

1. Take some very fine iron filings and mix them up with flowers of sulphur until the whole mass presents a uniform grey appearance. Put it into a crucible, and heat it: the iron and sulphur, which are elementary bodies, unite at once and form a compound substance, **sulphide of iron**. Before heating, it would have been possible by mechanical means, such as the dissolving out of the sulphur by means of carbon disulphide, to separate the minute particles of each substance, and obtain the iron and the sulphur in separate masses, although to the eye the mass was apparently homogeneous. In fact, before heating, the two substances formed what is known as a **mechanical mixture**; whereas, afterwards, they are changed, and, by uniting, have become what is known as a **chemical compound**. *By imparting energy in the form of heat to the minute particles of iron and sulphur we have enabled them to combine chemically.* If iron sulphide be powdered up into the very minutest particles that we can see with a strong microscope, each particle we thus see will contain both sulphur and iron, whereas, before heat was applied, any single small fragment of the mixture might have been either iron or sulphur.

2. Into a eudiometer introduce 100 cubic centimetres of hydrogen gas, and also 50 cubic centimetres of oxygen. The two will form a uniformly invisible mass. It is impossible to distinguish either element by merely looking at it. As the gases are, however, only *mechanically mixed* it is possible to take away one and leave the other. Pyrogallie acid will absorb the oxygen and leave the hydrogen. As soon, however, as we apply energy in the shape of an electric spark to the mixture, the entire nature of the mixed gases changes. They disappear, and we get a small quantity of water formed instead: this is a *chemical* compound formed by **synthesis**. The smallest particle of it will contain both gases, and it will require a considerable amount of energy to separate them again by the process of **analysis**.

3. Take some magnesium powder or ribbon, weigh it carefully, and then burn it in a crucible, of which you have previously ascertained the weight. Collect and weigh the oxide of magnesium, the white powder which is formed. Repeat this experiment three times, always using different quantities of magnesium. You will find that the increase of weight always bears a certain proportion to the magnesium you used. The more you repeat the experiment the more obvious will this fact become. Experiments of this kind lead us to believe, that when elements are brought into chemical combination, they *invariably unite in certain definite proportions*. This conclusion will be further strengthened, if, by modifying the last experiment, you vary the quantities of oxygen and hydrogen. Unless there is double as much hydrogen as oxygen, you will get some of either one gas or the other left over at the end.

4. As further examples of synthesis, and also as examples of the fact that substances, when combining with oxygen, take up different quantities of that gas, heat in open crucibles similar weights of lead, tin, zinc, and magnesium and compare carefully the weights of the oxides found in each case. It will be necessary, in order to oxidise the whole mass, to keep a fresh surface of metal constantly exposed to the air.

Or, if the experiment be done more carefully, by passing oxygen gas slowly over each metal, we shall find that the ratio of the weight of the metal to the weight of the oxygen with which it unites is constant for each metal. And if we examine copper oxide prepared from the metal, or by heating the nitrate of copper, or the carbonate of copper, we shall find that the ratio of the quantity of copper to the quantity of oxygen does not vary.

From experiments such as this we deduce a most important law, namely, that **any given compound always consists of the same elements combined together in the same proportions.**

Further experiments to prove this law :—

(a) Heat varying quantities of chlorate of potash ; the amount of chloride of potash obtained will always bear a certain relation to the amount of chlorate of potash taken.

(b) Heat to redness pieces of chalk, marble, or limestone, and note the relation between the amounts of lime left and chalk taken.

(c) Heat the nitrates of copper, magnesium, bismuth, or lead, and note the relation between the amount of nitrate taken and the amount of oxide left in each case.

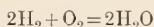
MODES OF CHEMICAL ACTION.

In many of the foregoing experiments, such as the oxidising of copper and magnesium, the burning of a candle, and the

combination of iron and sulphur, we have effected a *chemical change*.

The name given to *that form of energy* which brings about changes such as these—the combinations of bodies to form entirely new substances with distinct properties—is **chemical affinity**. We cannot say definitely, how this form of energy is enabled to bring about such results as it does. But it appears to be connected with the motions of the minute particles of which matter is composed. There are many different ways in which chemical action may take place, but the following may be taken as typical examples:—

1. *Simple synthesis* or combination of the molecules of two elements.



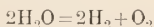
Hydrogen and Oxygen yield Water.

Of similar nature is the combination of the molecules of two compounds, thus :

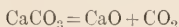


Ammonia and Hydrochloric acid yield Sal-ammoniac.

2. *Simple analysis*, that is, the splitting up of a compound body into its constituents.

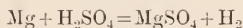


Water yields Hydrogen and Oxygen.



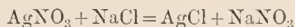
Chalk yields Lime and Carbonic acid.

3. *Single decomposition*, when an atom, or group of atoms, in a compound body is displaced by another atom, or group of atoms.



Magnesium and Sulphuric acid } give { Magnesium sulphate and Hydrogen.

4. *Double decomposition*, when two bodies both undergo decomposition, and two new bodies are formed.



Silver nitrate } and { Common salt } give { Silver chloride } and { Sodium nitrate.

Chemical affinity, to recapitulate, is perceived in such occurrences as the sudden combination of hydrogen and chlorine, the slower combination of oxygen and iron, the absorption of carbonic acid by lime, and the combinations of sulphur and iron, phosphorus and iodine, etc. In all these cases, as indeed in all chemical actions, *the ratios of the amounts of the bodies taking part in them are invariable*. Wherever new bodies are formed by combination, or compound substances on decomposition, there is a *fixed proportion* of each substance taking part in each reaction. This quantitative character of chemical action is exemplified by the experiments given in the foregoing page, and by others on similar lines, such as:—

1. Heat silver nitrate in an open crucible. It is decomposed; and eventually silver is formed in the crucible. By doing the experiment two or three times, we arrive at the ratio of silver in silver nitrate, and this will be found to be invariable.

2. Heat some iodate of silver. It loses oxygen. If the same quantity be always taken, the loss of weight will be identical each time the experiment is made.

3. Pass some coal-gas through a hard glass tube in which you are heating a *known weight* of copper oxide. The oxide loses its oxygen, and copper is formed together with water, which goes off as vapour. We are thus enabled to find the amount of copper in copper oxide, and the proportion of copper to oxygen will be found to be invariable.

4. If a known weight of magnesium is added to silver nitrate, sufficient in quantity to dissolve it, the quantity of silver precipitated will always be found to have the same ratio to the quantity of magnesium taken.

5. Similarly iron dissolves in a solution of sulphate of copper, and copper is precipitated. For the same quantity of iron dissolved, the same quantity of copper is always precipitated.

6. Dissolve a known weight of sodium carbonate in hydrochloric acid. Common salt is formed, and it can be collected by evaporation and weighed. The amount will always bear a fixed ratio to the amount of sodium carbonate used.

DALTON'S ATOMIC THEORY.

The Greek philosophers, at a very early date, enunciated the theory that matter was composed of minute particles called *atoms*, which were *indivisible*. Dalton at the beginning of this century revived this idea and gave to the world a systematic hypothesis,

which aimed at explaining the fact, that chemical compounds have an invariable composition. As a result of a long series of experiments on the hydrides and oxides of carbon, the oxides of nitrogen, water and hydrochloric acid, he arrived at the conclusion that, when chemical action took place between two elements, *it was due to the union of their atoms*. The atoms of the elements, he said, each had a **definite weight**; and it was in these relative weights that they combined with each other. Taking hydrogen as unity, he assigned to each element an **atomic weight**, which weight also represented *the combining proportion* of that element.

Aided by the experiences of Avogadro, we have nowadays *modified this theory* to a slight extent. We now consider that the smallest portion of an element that can exist in a free state is a **molecule**, which consists as a rule of two atoms.

The smallest part of any compound body that can exist free is *also a molecule*, which consists of two or more atoms.

Thus the smallest portion of hydrochloric acid that we can conceive must consist of one atom of H and one atom of Cl, but the smallest quantity of free hydrogen would be H_2 and the smallest quantity of free chlorine Cl_2 . When these unite we get two molecules of hydrochloric acid, written $2HCl$. *An atom, then, is the smallest quantity of an element that can exist in combination, and a molecule the smallest quantity that can exist free.*

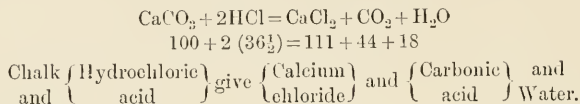
Symbols such as K, Na, S, O, Ca, are short forms of the names of the elementary bodies. Each symbol always represents a *certain numerical value*, which is *also the atomic weight* of the element, and the proportion in which it goes into or comes out of combination with other elements. (See table, p. 181.)

Formulae are short forms of the names of compounds, made up of two, or more, symbols. Thus $CaCO_3$ is the formula of chalk, which is thus shown to consist of—

$$\begin{array}{l} \text{One atom Ca} = 40 \\ \text{,, ,, C} = 12 \\ \text{Three atoms O} = 16 \times 3 = 48 \end{array}$$

$$\text{Total} = 100 = \text{molecular weight.}$$

Equations are short ways of writing down chemical reactions. Not only do they show what substances take part in the reaction, and what new substances are formed, but at the same time they give the quantities of each and all, thus—



If the equation be correctly put down, the total figures on one side should exactly balance those on the other.

EVAPORATION.

If we take a beaker of water from the laboratory tap, and boil it down until the whole of the water disappears, we find, as a rule, that there is a slight solid deposit left. (In localities where the water is very soft, this will not be the case.) This deposit may be collected in larger quantities by repeatedly filling the beaker, and boiling away the water. With sea-water, or an equivalent salt solution, the deposit is still more marked. This, then, is another method of separating substances. The clear water, as we draw it from the tap, shows no sign of containing solid matter; but we find when the water has gone, that the solid matter is now quite apparent.

We are enabled, by the process of evaporation, to estimate fairly accurately the amount of solid in any given solution.

Experiment.—For the sake of practice, evaporate down 50 cubic centimetres of any of the following reagents in the laboratory:—Sodium phosphate, caustic potash, barium chloride, silver nitrate, and give the *percentage strength* of each solution.

CRYSTALLISATION.

Take some common potash alum, and also some copper sulphate. Dissolve about equal portions of each in a beaker of water, until a considerable amount of each salt is *thoroughly* dissolved. Decant into an open glass vessel, or saucer, and put away carefully into some warm, and dry, place out of the way of the dust. In the course of a day or two the water will have evaporated, and we shall find that the two solid salts have separated

out from each other in the form of crystals, bodies having a regular and definite shape. Each substance will be noticed to have its own particular shape, and as the crystals are in one case blue, and in the other colourless, we can pick them out separately and examine them in detail.

Repeat the experiment by dissolving in separate portions of water salts such as nitre, magnesium sulphate, common salt, and zinc or iron sulphates. In each case pick out the largest crystals formed, and compare their shapes by examining carefully under a magnifying-glass.

To further study the properties of crystals, take a piece of calc-spar and break it up roughly by striking it with a hammer. Notice that the small fragments formed are all of the same shape as the original piece of spar.

Take several quartz crystals of different sizes, note carefully the shape in each case, and take rough measurements of similar angles in each specimen. They will all be found to be equal. This will also be noticed with the rhombic crystals of iceland-spar.

Crystals are bodies with a definite geometrical shape, *the similar angles of each particular kind of crystal are equal*, and crystals, when broken, break in certain definite directions called *lines of cleavage*. The slower the process of crystallisation, the larger and more symmetrical are the crystals formed. This can be shown by picking out some well-shaped alum crystals, and allowing them to grow in solutions of alum, until they have reached a large size. The process is a long one, as the heat, the rate of evaporation, and strength of solution, all require careful regulation. Alum crystallises in the form of a regular octahedron, or a double four-sided pyramid.

Bodies which take the same crystalline form are said to be *isomorphous*. If a substance crystallises in two different crystalline forms it is said to be *dimorphous*. Sulphur and carbon are dimorphous. Bodies which do not take any particular crystalline shape are said to be *amorphous*: example, charcoal.

We do not at present know why the molecules of some solid bodies are thus enabled to separate themselves out from a solution, each in its own particular shape; but a regular system of classifying these shapes, according to the *planes of symmetry*, has been worked out; and we are enabled to refer each crystal to its own class.

When several salts are dissolved in water, some will be found to crystallise out before others, and this fact is often made use of

for separating solids. When salts of unequal solubility, such as chlorate and chloride of potash, are dissolved in water, the former, being the more insoluble of the two, will be deposited before the latter, and they can thus be separated.

WATER OF CRYSTALLISATION.

Weigh out about half a gram of copper sulphate crystals, and heat in a crucible of known weight. When the blue colour has entirely disappeared, and the crystals crumbled away to a greyish powder, re-weigh. A definite loss of weight will be noticed. This is due to the fact that the crystals contained water which has been driven off by the heat. If we repeat the experiment several times, using a different weight of substance each time, we arrive at the definite proportion of water in copper sulphate crystals. This is a fixed quantity. If we supply the grey powder with water, and then evaporate slowly, the blue coloured crystals can be caused to reappear.

Treat, in the same way, crystals of magnesium sulphate, alum, or sodium carbonate, and find the amount of water of crystallisation in each case.

PRECIPITATION.

When a solution of common salt is added to a solution of silver nitrate, a *white cloudy substance* appears and sinks slowly to the bottom of the test-tube. If we filter this off, we note that it is apparently neither salt nor silver nitrate, both of which are colourless crystals, whereas the new substance is an amorphous white powder which becomes dark-coloured in the light.

The white substance is a *precipitate* of silver chloride. When two substances in a state of solution produce, by their reaction on one another, an insoluble compound, the latter will make its appearance as a precipitate. The newly formed body comes into existence as a solid on mixing the liquids.

Precipitation is largely made use of in the laboratory for the formation, quickly and easily, of many chemical substances which might otherwise be difficult to prepare. The little particles of each salt are so finely diffused throughout the liquid, that they are enabled to act at once on each other and form new substances. In the above case the other substance formed is sodium nitrate, which remains in solution. Precipitation, naturally, only occurs,

when two *dissolved* bodies act on each other. The liquid or gaseous condition is always conducive to chemical change.

DISTILLATION.

As already explained, this is a method employed for *separating a liquid from a solid*, or for *separating two liquids* of different boiling points.

If we wish to obtain pure water from a sample of water, which we know contains salt in solution, we can volatilise the water by means of a retort, and by condensing its vapour as it passes into a flask kept cool by cold water, we obtain in the receiver absolutely pure water.

If, however, we have a mixture of two liquids, such as alcohol and water, the former being more volatile will come off first, and if the temperature be kept at about 80° (not more), we can separate the alcohol from the water. The distillate may not be quite pure, as some water may have passed over as well, so by re-distilling again and again, a process which is termed *rectification*, we eventually obtain the alcohol pure and free from water.

Fractional Distillation is the term applied to the process of separating from each other several liquids of varying boiling points.

Experiments.—1. Find the boiling points of several different liquids, such as benzene, ether, alcohol, turpentine. In each case note results carefully, as a guide to experiments which follow for the separation of liquids.

2. By the process of distillation obtain pure water from a solution of sodium chloride, or barium chloride.

3. Distil a mixture of alcohol and water, and obtain as pure a sample as you can of the former. You can, by finding the density of the alcohol you obtain, form a rough idea as to how far you have been successful.

4. Try the same experiment with a mixture of water and ether. In this case heat the flask, containing the mixture, in a copper water-bath, and do not allow the thermometer to rise above 35° . Ascertain the density of the ether so prepared.

5. Using the more complicated form of apparatus known as a *Liebig's condenser*, separate a mixture of three liquids.

AIR.

The study of simple chemical facts may well commence with observations on common substances such as air and water.

Exhaust the air from a flask and weigh it: allow air to enter, and re-weigh; there will be a gain of weight. *The air has weight.* If you know the volume of the flask you can **ascertain the weight of a known volume of air.** This can also be done as follows:—Take a half-litre flask, put a little water in it, and fit it with a cork which has a glass tube through it connected with a piece of rubber tubing on which you can put a clip. Expel all air by boiling for several minutes. Clip the rubber tube, and weigh the whole apparatus. When cool, open the clip and allow air to enter; re-weigh. Knowing the volume of the flask up to the cork, and finding out the amount of water in it, we get by subtraction the volume of air which has entered; and the weight of this volume is the increase of weight found in second weighing. Careful experiments will give the weight of a litre of air as about 1.2 grams.

To find the density of air repeat either of the above experiments, but allow hydrogen to enter the flask. It will be found that it is about $\frac{1}{14}$ th of the weight of air.

Place a piece of phosphorus on a wire inside an inverted burette and leave it to stand several days over a beaker of water. The water will rise about $\frac{1}{5}$ th of the way, for the phosphorus has subtracted a gas from the air.

Repeat the same experiment, using this time some iron filings. The result will be similar. What is this gas? The following experiments tell us. Heat some mercury (or some lead) for the same length of time in air, until enough powder is found on the surface to collect and use for experiment. Heat the powder in a closed tube. Mercury (or lead) and an *invisible gas called oxygen* is formed. This gas can be recognised by its property of rekindling a glowing taper.

Make some oxygen by heating potassium chlorate and manganese oxide in a flask and collecting gas over water; compare its properties with the oxygen obtained from air. You will find them identical.

We have shown before, how substances such as lead, magnesium, iron, and mercury *increase in weight*, when they combine with the oxygen of the air.

The air contains **Oxygen**, and the volume of that gas is roughly $\frac{1}{5}$ th of the air. When oxygen is taken from the air by means of phosphorus (or iron), another gas is left. What are its properties? Experiment shows that they are entirely negative. A candle or taper will not burn in it. It will not dissolve in water.

It will not light. It will not affect litmus paper. It is very difficult to make it react with other elements. This gas is called **nitrogen**. The nitrogen, however, is not quite pure, for if we absorb it by heating magnesium in it, a small residue will be left; this is the *newly discovered gas* **Argon**. There are also very small quantities of *other gases* to be found in some samples of air. Though, as may be supposed, *the composition of air is very constant*, no one would imagine the air on a mountain side, or the sea, to be the same identically as the air of a heated and crowded room.

Expose to the air some freshly made lime-water in an open vessel. It becomes covered with a film of chalk owing to the **carbonic acid** in the room. Blow through a glass tube into some of the same lime-water; you get a thick white precipitate of chalk. Now you recognise the fact that the *breathing* of animals sends carbonic acid into the air. The amount of carbonic acid in the air of a room can be found by passing a known volume of air through a solution of caustic potash, which absorbs CO_2 , forming carbonate of potash (K_2CO_3). The process is a lengthy one, however.

Put a piece of ice, or some ice-cold water, into a dry glass beaker, the *outside* will become covered with drops of water. *This water comes from the air, where it exists as water-gas.* The presence of water in the air can also be demonstrated by leaving a large lump of calcium chloride (CaCl_2) standing on a piece of glass in a room: in a few hours the calcium chloride will absorb sufficient water from the air to become a liquid mass. Strong sulphuric acid in an open beaker will also absorb water from air, and gain in weight by so doing. Weigh both these substances before and after.

In some parts of the world traces of other gases are found; such as **ammonia** (NH_3) from decaying matter, **sulphur dioxide** (SO_2) from coal fires of towns, **ozone** (O_3 , a kind of condensed oxygen) on the seashore, and various other gases. These are not easily recognised by experiment in ordinary samples of air, as they exist in such very minute and varying quantities, and, indeed, are not always present.

The method used in finding the **composition of the air by weight** is, in brief, as follows. A known volume of air is passed slowly through a series of tubes and bulbs; the first set of bulbs contain caustic potash (KHO) solution, which absorbs the carbon dioxide (CO_2); the second set of U-tubes contain pumice stone soaked with sulphuric acid (H_2SO_4), these absorb the water; the next, a long tube of hard glass, contains heated copper which absorbs the oxygen, and the nitrogen passes over pure. The increase of weight in each set of the tubes gives amount of carbonic acid, water, and oxygen, and the weight of the nitrogen can be deduced from its volume.

The method of finding the **composition of the air by volume** may be understood from the following experiment. A known volume of air stands

over mercury in a graduated tube. Sufficient hydrogen is passed up to combine with the oxygen, which we have already discovered to be about $\frac{1}{5}$ th of air. The mixture is exploded, and the volume will be found to have decreased by about $\frac{1}{5}$ th. The experiment with phosphorus also gives us the relative volumes of nitrogen and oxygen, or we can absorb the oxygen with pyrogallic acid.

Air, or rather the oxygen of the air, dissolves in water. If freshly boiled water be shaken up with air, it will be found, on gently heating it, to have absorbed some oxygen, which can be collected and tested. Fishes, and other animals living in water, obtain their oxygen from the air, which is always giving some of its oxygen, by solution, to water.

Quite lately air has been converted, by means of extremely low temperature and great pressure, to a transparent liquid.

Animals *inhale* the oxygen of the air, and *exhale carbonic acid*; plants, roughly speaking, *exhale oxygen*, and *take in carbonic acid*. All carbonaceous matter, when burning, adds to the quantity of carbon dioxide in the air. **Combustion** in air is, in fact, the union of bodies with the oxygen of the air, as seen in the burning of a candle, of coal-gas, of phosphorus, magnesium and sodium, etc. If the chemical action be sufficiently strong, **flame** will be seen, but if the action be a slow one, such as the rusting of iron (a slow oxidation), the evolution of heat is spread out over so long a period that no visible effect is produced. **Thermal change, however, always accompanies chemical action.**

If a weighed quantity of magnesium wire be burnt in the air, it gives out a brilliant light and forms a certain quantity of magnesium oxide (MgO), a white powder. The same quantity of magnesium, however, if allowed to rust away in moist air slowly, will evolve just as much heat, and give just as much magnesium oxide, but there will be no visible flame, as the evolution of heat, though equal in amount to that in the first case, is so much more gradual.

The phenomena of *combustion* are not confined to air and oxygen: for instance, many substances, such as powdered antimony, or phosphorus, will burn in chlorine. The terms "*supporter of*

combustion” and “*combustible*” are merely relative, as may be shown by causing air to burn in an atmosphere of coal-gas, which is done by forcing air slowly through a tube into a vessel (such as a lamp glass) supplied with coal-gas. A light applied to the air tube inside the lamp glass will cause a flame to appear where the air meets the coal-gas.

Flame is due to particles of gas becoming so hot as to be self-luminous. The denser the gas, as a rule, the more luminous is the flame. The flame of hydrogen burning in air, though extremely hot, is practically non-luminous, owing to the low density of the hydrogen.

If we stop up the holes at the bottom of a bunsen burner, the temperature of the flame falls, the combustion is not so complete, and the flame becomes luminous. Apparently particles of carbon in the coal-gas become *white-hot* and *emit light*. Directly we open the holes, and admit more air, the flame becomes hotter, combustion is more complete, and the particles of carbon are at once *burnt up* into carbonic acid, *before they have time to get white-hot*.

The presence of solid particles in a flame may give rise to different qualities of light. If we shake finely powdered sodium carbonate into a bunsen flame, it emits a yellow light. Calcium salts colour the flame red, copper salts impart to it a greenish colour.

A candle flame, like a gas flame, consists of three distinct zones: (1) an inner blue non-luminous part, consisting of unburnt hydrides of carbon, (2) luminous zone where the gases are burning, (3) outer invisible zone of burnt gases, viz., water and carbonic acid. Bodies which give out a bright light when very hot are said to be *incandescent*. Heat, on platinum foil or wire, small quantities of the oxides of aluminium, calcium, magnesium, or barium; they glow brilliantly. The oxy-hydrogen limelight is an example of the practical use of **incandescence**.

WATER.

Before considering in detail the more important chemical properties of water it will, perhaps, be as well to recapitulate the

physical properties of that liquid which have already been pointed out in preceding pages.

Water is solid at a temperature below 0° C., between 0° and 100° it is liquid, and above 100° it is gaseous. This is only a general statement, as under special circumstances, such as extreme stillness, or great agitation of the surface by wind, water remains liquid sometimes below 0° , as is also the case if it contain large quantities of saline matter. The boiling point also varies with the pressure of the atmosphere. In fact, if we simply state, that water boils *when the pressure of its vapour is equal to that of the superincumbent atmosphere*, we are more accurate than when we say, that the boiling point is 100° . Large amounts of dissolved matter will also raise the boiling point.

It must not be forgotten that to convert one gram of solid water into liquid, we require an amount of energy represented by 79 *thermal units*, and to convert the liquid into steam the amount required is 536 *thermal units*. Conversely, this energy, which is absorbed in passing from solid to liquid, and liquid to gas, is given out in the reverse processes of condensing from steam to water, and water to ice.

The point of maximum density of water is 4° C., and, when at this temperature, water forms the standard by which we measure the densities of all other solids and liquids. Water cannot be compressed. It is a very bad conductor of heat.

COMPOSITION OF WATER BY VOLUME.

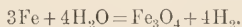
When water is decomposed by electrolysis in a two-tubed voltameter, it is found that the volume of hydrogen given off is twice that of the oxygen. This experiment should be made, and the gases should be tested. The distinctive property of the oxygen, its power of rekindling a glowing taper, should be noted. The hydrogen may be lighted at a jet, and if a cool glass be held over the flame, water re-forms. The composition of water is expressed by the formula H_2O . This formula is verified when water is produced from its elements in the eudiometer. Unless we pass exactly twice as much hydrogen as oxygen into the tube before

exploding, one or other of the gases will be found in excess after the spark has passed. The relative volumes of the component gases, taken in conjunction with Avogadro's hypothesis, enable us to make the statement, that H_2O represents a molecule of water.

COMPOSITION OF WATER BY WEIGHT.

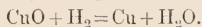
Take a hard glass or iron tube, and fill it partially with iron filings; pass over the filings steam, from water boiling in a flask. The iron should be heated to bright red heat. As the dry stream passes over the heated filings it is decomposed, the iron combines with the oxygen, and the hydrogen passes on free.

If the weight of the filings be taken carefully, before and after the experiment, and the weight of water used be known, we get the weight of the oxygen, and hence, by subtraction, the weight of the hydrogen in a known quantity of the liquid. The reaction is represented by the following equation:—



From this we find that the proportions of oxygen and hydrogen by weight are as 8 to 1. We can further verify this by synthetically building up water from its constituent gases in these proportions by weight.

Again, dry hydrogen, generated from zinc and dilute sulphuric acid, is passed over a known weight of copper oxide heated in a hard glass tube. The copper oxide loses oxygen and water is formed; this may be collected and weighed. If the loss of weight of the copper oxide be subtracted from the weight of the water formed, we get the hydrogen used in the experiment, and we shall again find that the proportions are oxygen 8, hydrogen 1. The reaction which takes place may be expressed—



DIFFERENT KINDS OF WATER FOUND IN NATURE.

The purest form of water is **rain-water**, which, on being boiled down, leaves no solid residue, just as is the case with **distilled water**. In fact rain-water is practically water distilled by the heat of the sun. **Spring-water**, such as is generally used for domestic purposes, varies very much in purity. In districts where the rocks, through which the springs find their way, are of granite, or primary geological structure, the water is nearly pure. Owing, however, to *its great solvent properties*, water in passing through other strata is enabled to *collect various*

soluble salts, which may be obtained from it and analysed. **Hard water** is so called because it will not easily make a lather with soap. There are two kinds of hardness—*temporary*, caused by the presence of chalk, and *permanent*, caused by the presence of gypsum. Chalk is insoluble in water under ordinary conditions, but when the water takes up carbonic acid gas, it is then enabled to dissolve the carbonate of calcium it meets with. If this gas be driven off, the water can no longer hold calcium carbonate in solution. It falls as a precipitate, and the hardness disappears. Permanent hardness can only be got rid of by distillation. **River-water**, and **pond- or lake-water**, resemble spring-water, but are likely also to contain varying quantities of suspended organic matter, and dissolved nitrogenous substances due to the presence of decaying animal and vegetable matter.

Mineral-springs, which occur in various parts of the world, are distinguished by the presence of *some particular dissolved mineral*, thus *chalybeate* springs contain iron salts; *sulphur* water contains sulphuretted hydrogen; many (such as *Apol-linaris*) contain large quantities of carbonic acid, others contain sodium salts (natron springs), and magnesium salts are found in the Epsom springs.

Sea-water.—In addition to all the impurities contained in spring- and river-water, we find in sea-water many other salts, such as *chlorides*, *bromides*, and *iodides*, of the *alkali metals* and alkaline earths. The amount of solid matter in sea-water averages about *36 grams in a thousand of water*. Most of the solid matter has been brought down to the sea by the rivers. The sea consequently has a tendency to become more and *more salt*. In places where evaporation is very rapid, and there is no outlet for the water, the water becomes more and more saline, as in the Dead Sea.

Experiments.—(a) Into different beakers put samples of distilled water, rain-water, hard spring-water, river-water, sea-water, and pond-water, and test as follows, *carefully tabulating results*. Add silver nitrate to a portion of each; a white precipitate, varying in thickness, may or may not be noticed. This precipitate shows *presence of some chloride*, probably sodium chloride, or common salt.

(b) Add barium chloride to a portion of each ; a fine crystalline precipitate *indicates presence of sulphates*, probably calcium sulphate (CaSO_4).

(c) Boil down about a pint of each, note *amount of residue* (if any) in each case. Collect it carefully. Put some on a clean platinum wire and hold in bunsen flame, a *red coloration indicates presence of calcium salts*. Add a little acid (hydrochloric is suitable) to the residue ; if it effervesces, it shows that *carbonates are present* in the residue.

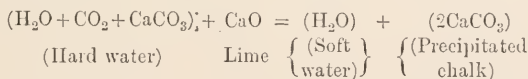
(d) Take some of the “fur” or precipitate from a kettle or boiler and apply the last two tests to it. The flame coloration is very evident, and the carbonic acid gas given off can be made to turn lime-water milky.

(e) Put some finely powdered chalk into distilled water and stir well, *it will not dissolve*. Now pass into it plenty of carbonic acid gas (made by placing pieces of marble in hydrochloric acid in a flask and leading the gas into the water by means of a tube), the chalk dissolves. Take the clear solution thus formed and boil it ; the gas rapidly goes off, and the chalk is slowly precipitated again.

(f) Compare this with the effect produced by blowing into lime-water for some time.

(g) Add a clear solution of soap to each of the above samples of water. Notice if the water forms a precipitate (which would be a mixture of the *stearates, palmitates, and oleates of calcium*), or if it lathers showing whether water be hard or soft.

(h) Take some water which you know contains calcium carbonate held in solution by carbonic acid gas. Add to it some quicklime and notice the precipitate formed. This process, known as *Clark's process*, is largely used for the softening of water which is very hard. The following equation explains the reaction :—



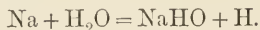
THE CONSTITUENTS OF WATER : HYDROGEN.

The hydrogen in water can be obtained therefrom—

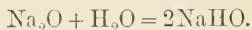
1. By electrolysis (see p. 196).
2. By passing steam over red-hot iron filings (see p. 197).
3. By placing a small piece of potassium or sodium, wrapped up in wire-gauze, under water, and catching the gas which escapes in a gas jar filled with water, and held over the sodium.

The metals of the alkalis, of which sodium or potassium are the commonest, *are able to decompose water at the ordinary tem-*

perature. They unite eagerly with oxygen and set free hydrogen, thus—



NaHO is *caustic soda*, or *sodium hydrate*, and it is formed by the solution of the sodium oxide first formed in the water, thus—



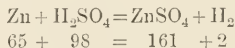
The reaction is just the same for potassium, KHO, *caustic potash*, being left in solution and hydrogen set free.

If the metals are placed on the top of the water, on which they will float, the hydrogen escapes into the air. It may be lighted, and the really colourless flame will be tinged yellow by the sodium particles and lavender-coloured by potassium.

4. Hydrogen may also be obtained very readily from certain of the common acids, such as sulphuric acid (H_2SO_4) and hydrochloric acid (HCl), when certain metals, such as zinc, magnesium, iron, or aluminium, are placed in them.

Take equal weights of zinc and magnesium (about 250 milligrams is a convenient amount) and place each kind of metal under a graduated glass tube filled with water and supported in a vessel of water. Bring the tubes down almost to the bottom of the vessel and directly over the metals. Add sulphuric acid. By liquid diffusion, this will reach the metals, and *gas will at once be liberated*. The action will continue until the metal has entirely disappeared, and the tubes will contain a certain volume of colourless gas, which can be proved to be hydrogen. It will be found that *the volumes differ*, although we measure them under similar conditions as to temperature and pressure. But *the ratio of the volumes is constant* whatever equal quantities we take of the metals, and moreover this same ratio is maintained when we use hydrochloric instead of sulphuric acid.

Further Experiments.—1. Making use of equations, such as—

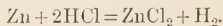


Zinc and Sulphuric acid = Zinc sulphate and Hydrogen,

find by calculation the volumes of H given off by one-third of a gram of zinc, magnesium, and aluminium, and *prove your quantities by experiment*.

(*Note.*—It will be seen from above that 65 grams of zinc give 2 grams of hydrogen. One gram of H occupies at 0° and 760 millimetres pressure a space of 11,200 cubic centimetres.)

2. Repeat the above, using hydrochloric acid ; thus—



PROPERTIES OF HYDROGEN GAS.

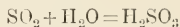
It has no colour, no taste, and when pure, no smell. Make some in a test-tube or flask from hydrogen sulphate. If the test-tube be corked, and supplied with a glass jet, the hydrogen can be lighted (when all the air has been expelled from the vessel), and will burn with a non-luminous flame, forming water with the oxygen of the air. This can be collected in a vessel, held over the flame and kept cool with a damp cloth. Mix equal quantities of hydrogen and air in a soda-water bottle and apply a light. The mixture explodes. Hydrogen can be *poured upwards*, for air is $14\frac{1}{2}$ times heavier than this gas. See if it will affect lime-water, when bubbled through it, or wet litmus paper held in it.

OXYGEN : ITS PREPARATION AND ITS PROPERTIES.

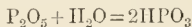
This element, as we have seen, is to be found both in air and in water. Indeed, it is the commonest of all the elements. It comprises $\frac{8}{100}$ ths of the weight of water, and 23 per cent. of the weight of the air. In fact it has been roughly estimated to form half the weight of the earth. *It is obtained*, as we have already seen, *from water* by the process of electrolysis. And it has also been *abstracted from the air* by two different processes. One of the earliest ways of making oxygen was to heat a bowl of liquid mercury in the open air until a thick coating of the oxide had been obtained. This was collected and heated in a closed vessel, the resulting products being oxygen and mercury. The other method is somewhat similar. Barium monoxide (BaO) is heated in the air until it becomes barium dioxide (BaO_2). This, on being re-heated to a higher point, separates out again into barium monoxide and oxygen. There are, however, *more convenient ways of preparing oxygen in the laboratory*. If potassium chlorate (KClO_3) be heated with a little black oxide of manganese (MnO_2) in a flask, it gives up the whole of its oxygen and becomes potassium chloride (KCl), and the gas liberated may be conveniently collected by displacement of water in the pneumatic trough. The oxide of manganese remains unaltered, and is only used because it

assists the evolution of oxygen in a more continuous and less violent manner. Prepare three or four jars of oxygen by this process, and notice that when pure it has *no colour, taste, or smell*. It will not light, but will rekindle a glowing piece of wood. We have seen already that it *dissolves slightly in water*. It will not affect lime-water if the two be shaken up together. **When elements are burnt in oxygen they form oxides**, and, with only **one exception**, **all elements unite with oxygen to form oxides**. Oxides are divided into three classes according to the properties they possess.

Experiments.—1. In three separate jars of oxygen burn each of the following: sulphur, phosphorus, and charcoal. Notice that the combustion is far more energetic than in the air. Sulphur and charcoal form invisible gases, sulphur dioxide (SO_2) and carbon dioxide (CO_2), phosphorus gives dense white fumes of pentoxide of phosphorus (P_2O_5). Shake each gas up well with water and test the liquid with blue litmus. It will turn red, showing that the oxides are all **acid**.



Sulphur dioxide and Water give Sulphurous acid.



Phosphorus } and Water give { Phosphoric
pentoxide } acid.

Acids are bodies with a sharp and bitter taste: they are able to change to red several vegetable blue colours, such as litmus. The stronger acids, such as sulphuric, nitric, and hydrochloric, dissolve most metals, *forming salts*, and they *destroy organic matter*. All acids when added to carbonates disengage carbonic acid gas. With bases they form salts (see below).

2. Place a little piece of metallic sodium in the deflagrating spoon, warm it, and place it in a fresh jar of oxygen. It inflames, forming an oxide Na_2O , which is typical of the second great class of oxides, the **alkalies**, or basic oxides. To this class belong the oxides of potassium, calcium, magnesium, etc.

Alkalies or bases are exactly opposite to acids in their properties. They turn red litmus blue. They have a soapy, caustic taste. They neutralise acids, combining with them to form salts. They have no action on carbonates. Strong alkalies *dissolve organic matter*.

3. Take some of the mixture, which has been used for the preparation of oxygen and is no longer needed, break up the fused black mass, and shake it up well with water. Filter it, and observe the residue, the black oxide of manganese. This is a **neutral oxide**, and *it has neither acid nor basic properties*. Water is a good example of a neutral oxide.

4. **Salts.**—Evaporate down the filtrate obtained in the above experiment, until you get a dry white salt, resembling common salt in taste; this is potassium chloride. It will serve as an example of a **typical salt**. It is made from a basic oxide or hydrate (KHO) and an acid (HCl).

5. Take some caustic potash solution and add it to hydrochloric acid until the mixture is neutral to litmus, then evaporate down, and you get exactly the same substance as you did when you drove off the oxygen from the chlorate of potash.

These important types of substances, acids, bases, and salts, will be considered more in detail at a later stage.

Oxygen is *essential to the life of an animal*. It is inhaled into the lungs, and eventually unites with some of the carbon in the animal tissues to form carbonic acid, which is exhaled by all animals. Plants, under certain conditions, exhale oxygen and inhale carbonic acid. Oxygen may be liquefied, and even solidified by great cold and pressure.

QUESTIONS AND EXERCISES ON CHAPTER VIII.

1. How would you experimentally separate—

(a) A mixture of fine white sand and sugar;

(b) Mud and clear water mixed;

(c) Sugar and water when the former is dissolved in the latter?

How would you in each case find the exact amount of each substance present?

2. Explain the terms "solution" and "diffusion." Name some liquid which will dissolve in another, and also some gas which will dissolve in a liquid.

3. Give briefly reasons for supposing that matter consists of small particles, and explain clearly the meanings of the terms "atom" and "molecule."

4. Heat a piece of iron wire in the bunsen flame, and treat a piece of magnesium wire in the same way.

Heat some powdered sugar in a test-tube, and treat some sal-ammoniac in the same way in another tube.

From results you obtain in these two experiments, explain the difference between a "physical" and a "chemical" change. Further illustrate your answer by explaining the difference between "electrolysis" of water and "distillation."

5. Heat small quantities of iodine, ammonium chloride, and lead nitrate. Plug the vessels with cotton-wool. Compare the changes taking place, and closely investigate the substances when they are cold.

6. Perform and describe some chemical experiment which will prove, that there is no alteration in the total amount of matter taking place in the chemical change.

7. How would you distinguish between the chemical and physical properties of some element you know of, oxygen for instance?

8. How would you prepare a solution of salt which would contain .25 grams in 5 cubic centimetres?

What is meant by a 10 per cent. solution of silver nitrate?

Find out practically the amount of common salt, potassium chlorate, and nitre, which will dissolve in 100 cubic centimetres of water at 15°C .

9. Find out by experiment the amount of water of crystallisation contained in 5 grams of washing-soda.

10. If 50 cubic centimetres of hydrogen and 40 cubic centimetres of oxygen are exploded in an eudiometer, what gas and what volume of it will be left over?

11. An eudiometer contains 35 cubic centimetres of air: what amount of hydrogen must be used to combine with all the oxygen present? What gas, and what amount of it, will be left over?

12. Give reasons for supposing that the air is a mixture of gases, and not a compound.

13. Calculate the amount of air required to completely oxidise half a gram of magnesium wire.

14. Give a few reasons for supposing that matter is indestructible.

15. How would you proceed to find the weight of one litre of coal-gas?

16. Name the three classes of oxides, and by comparing their properties distinguish carefully between them.

17. Mention and describe the different modes of chemical action. Give one illustration of each.

18. Distinguish between the atomic weight and the molecular weight of an element. Explain clearly how atomic weights are determined by Avogadro's law. How may the atomic weight thus determined be checked?

19. State the law of combination in definite proportions, and give an account of the experiments you would make to prove the law.

20. Describe the method of determining accurately the ratio of the volumes of oxygen and hydrogen which combine to form water.

21. What is the constitution of pure air? What impurities are usually present (1) near a large manufacturing town, (2) in a room containing a large number of people?

22. Describe an experiment showing that two volumes of hydrochloric acid gas contain one volume of hydrogen. What conclusion depending on Avogadro's law can be drawn from this fact?

CHAPTER IX

SOME OF THE MORE COMMON ELEMENTS AND THEIR COMPOUNDS

Carbon, after oxygen and hydrogen, is one of the *most widely distributed elements*, for it not only occurs in all animal and vegetable matter, but combined with metals and oxygen (as carbonates) it is a constituent of huge mountain masses. We have seen that it occurs in the air and water as carbon dioxide.

Diamond is a naturally occurring form of pure carbon, as is also **graphite** or black-lead. These two substances are proved to be the same by burning equal weights of both in oxygen, when equal weights of carbon dioxide (and nothing else) will be formed. Amorphous forms of carbon are seen in substances such as **charcoal** and **coke**. Neither of these is pure carbon, as they both contain varying quantities of mineral ash. Still more impure forms of carbon are **lamp-black**, **soot**, **bone-charcoal**, and **coal**. The amount of carbon in coal *varies with the age of the coal*. Brown coal or **lignite**, the youngest form, contains only 60 per cent., whereas **anthracite** contains over 90 per cent. Carbon unites with oxygen in two different proportions, but one is far more common than the other, for, whenever there is plenty of oxygen, *carbon dioxide is always produced* by the burning of carbonaceous matter.

Experiments.—1. Take a cube of *boxwood* (length of side about 2 centimetres), weigh it. Bury it well in sand contained in a crucible, and heat it till completely charred. When cool, re-weigh: the loss of weight is due to the gases O, H, N, etc., which have gone off. This will give you a rough idea of the proportion of carbon in vegetable matter.

Now heat the cube in the open air, until the black colour has disappeared

and nothing but white ash remains. Re-weigh and find the amount of mineral ash present.

Add a drop of acid to the mineral ash, if it effervesces it will show that there is still a little carbon left as carbonate (of potash).

2. Break up some wood into small fragments and heat in a closed test-tube. Note that an inflammable gas comes off (light it), that an acid liquid (test it) of dirty brown colour also comes out, and that charcoal is left.

3. Repeat the above experiments with a fragment of solid bone. Notice that the amount of carbon is much smaller, and the ash (phosphate of calcium) much bigger. The liquid also will be found to be alkaline.

4. Find the amount of weight lost in heating in closed tubes equal quantities of anthracite and lignite.

5. Invert a jar of ammonia gas in a basin of mercury, and place in it a piece of freshly made wood-charcoal. The mercury will rise rapidly to the top, and the gas will disappear into the charcoal. *Charcoal* is a great absorbent of gases, and as such is *used as a disinfectant*.

6. Pour some indigo solution through several thicknesses of bone-charcoal. Boil a little claret (or litmus) with some bone-charcoal in a test-tube and filter. In both cases colourless liquids result. *Charcoal absorbs many kinds of colouring matter.*

7. Take a known weight of charcoal and heat it in a tube through which oxygen is passing slowly. Collect the resulting gas in bulbs containing caustic potash solution. *The gas formed is carbonic acid.* (A sample of it can be tested with lime-water.) If we know the weight of the carbon dioxide formed in the bulbs and the weight of the charcoal used, we can ascertain the proportion in which carbon unites with oxygen. This will be found to be 12 of carbon to 32 of oxygen.

8. Repeat the experiment with some other form of carbon.

9. Burn various other forms of matter containing carbon, and note that the product is in each case carbonic acid gas. Suitable examples are methylated spirit, a candle, coal-gas, starch. These may be burnt in a large jar, and the products of combustion be shaken up with lime-water, when it will be found that CO_2 is formed in each case.

10. Note that *the breathing of animals produces CO_2* . Hence it is fair to assume that the evolution of CO_2 is connected with the oxidation of carbon, in some form, in the body of the animal. This is really the case, the carbon in the blood is oxidised in the lungs by the process of respiration.

11. Note that whereas diamond is the hardest and most refractive substance known, graphite is soft and greasy to the touch, and in the form of common *black-lead* is used for lubricating purposes. Compare the marks made on paper by black-lead, charcoal, and real metallic lead, and you will understand the origin of the very misleading name of the first.

OXIDES OF CARBON.

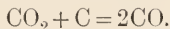
Take a hard glass tube, and fill it half full with fragments of charcoal. Heat the tube to red heat and pass slowly over the charcoal some carbon dioxide, made from marble and hydrochloric acid. The gas which issues from the end of the tube will be found to be entirely different from carbon dioxide.

(a) It will not precipitate lime-water.

(b) It will burn, forming CO_2 .

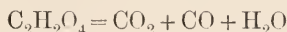
(c) It is insoluble in water.

This gas is **Carbon Monoxide (CO)**, formed by the addition of an atom of C to the CO_2 , thus—



It may be often seen in any clear fire, as a pale-blue flame burning on the top of red embers. The carbon dioxide formed at the bottom, and in the interior, of the fire, in passing over the red-hot carbon higher up becomes converted into carbon monoxide, which catches fire again at the top of the grate, and passes up the chimney as carbon dioxide.

The two oxides of carbon may be prepared simultaneously by heating in a flask some oxalic acid and a little strong sulphuric acid, thus—



Oxalic acid yields Carbon dioxide, Carbon monoxide, and Water.

The CO_2 may be absorbed in caustic potash, and the CO will pass on and can be burnt. Carbon monoxide is a *highly poisonous gas*, whereas the dioxide possesses merely suffocating properties. The monoxide, together with hydrogen, forms the so-called *water-gas*, which is used as fuel in several important manufactories. Carbon monoxide is also a very useful *reducing agent*; that is, it takes away oxygen from different substances, and reduces them to the metallic state. The large quantities of iron turned out by the blast furnaces are produced by the aid of carbon monoxide, which takes away the oxygen of the ore. This may be shown in the laboratory by passing a stream of the

monoxide over copper oxide heated in a glass tube, metallic copper and carbon dioxide being formed.

Carbon Dioxide is readily produced by the action of any acid on any carbonate. Perhaps the best way of making it is by the action of hydrochloric acid on marble, in a flask. The gas formed can be collected in long gas jars, by displacement of air.

The following experiments illustrate the more important properties of carbon dioxide:—

1. It extinguishes a lighted taper. Try this in a jar of gas. And note also that CO_2 will not burn.

2. Counterpoise a beaker on the balance, and pour into it CO_2 from the gas jar. Being heavier than air, carbon dioxide can be poured just as water is, and the beaker will at once be seen to become much heavier.

3. Pass some CO_2 into a test-tube containing a little powdered chalk suspended in water. *The chalk will dissolve when the water is saturated with the gas.*

4. Pass some of the gas into water, and notice that the water has an *acid reaction to litmus*, but feebly so.

5. Pass some of the gas into caustic potash solution. If you know the weight of solid caustic potash in the solution at starting, and then evaporate down the solution after the CO_2 gas has been passed in for some time, you will notice a *considerable increase of weight*. The white salt left is no longer caustic potash, but *potassium carbonate*, K_2CO_3 .

6. Try some of the above experiments with the gas given off from soda-water or any similar effervescent water. It will be found to be carbon dioxide, the best test for which is, as often mentioned before, the fact that it turns lime-water milky.

CARBONATES.

Carbonic acid unites with most bases, forming an important class of salts called **carbonates**. Of these many occur in great quantity in the earth, thus **chalk**, **limestone**, and **marble** are carbonate of calcium, CaCO_3 . **Dolomite**, which forms large mountain masses, is a mixture of magnesium and calcium carbonates. The carbonates of iron, barium, and copper are also common.

Carbonates are mostly *insoluble salts*, and they are *easily decomposed by heat, or by the action of acids*. Any acid will set free carbonic acid gas from any carbonate, so feeble is the combination of the acid with the metallic base.

Some few metals, such as sodium and potassium, have two carbonates; thus we have *sodium bicarbonate*, NaHCO_3 , and *ordinary sodium carbonate*, Na_2CO_3 (commonly called *soda*). The former is made from the latter by passing carbonic acid gas into a solution of Na_2CO_3 . As will be seen from the formulæ, the difference in composition of the two consists in the fact, that one contains one atom of hydrogen and one of sodium, whereas the other contains two atoms of sodium. (See Sulphates, p. 216.)

COMPOUNDS OF CARBON AND HYDROGEN.

There are many important compounds of hydrogen and carbon, but of these, three alone need be considered briefly here. The first is a naturally occurring gas, CH_4 , **methane or marsh gas**, or light carburetted hydrogen. It may be collected from almost any pond by stirring up the bottom, and allowing the bubbles which rise to collect in a jar of water. In the laboratory it may be made by heating together acetate of sodium and caustic soda. It can be collected by displacement of water, and the following properties noted:—

It has *no colour, taste, or smell*. Next to hydrogen it is the lightest gas known, and is *insoluble in water*. It burns with a non-luminous flame, forming *carbon dioxide* and *water*. Mixed with air it explodes violently.

It is one of the constituents of coal-gas, and as it is given off freely from coal it is often the cause of disastrous explosions in mines. When it becomes mixed with air and comes in contact with a naked flame, it explodes at once. It is called "**Fire-damp**" by miners, and its after-product, carbon dioxide, is termed "**Choke-damp**."

Methane is a *saturated compound*, that is to say, each atom of carbon is united to the maximum amount of hydrogen, viz., four atoms. It is therefore able to form compounds by substitution only. Thus, chlorine may take the place of some of the hydrogen as CHCl_3 , chloroform.

Ethylene or olefiant gas, C_2H_4 , is familiar to us as the principal constituent of coal-gas. It is easily made in the

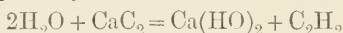
laboratory by warming together in a flask, alcohol and strong sulphuric acid.

As it is *insoluble in water*, the gas may be collected in the ordinary way over the pneumatic trough.

Make and collect some gas, and note the following properties. It is *colourless*, it has *sweetish smell and taste*, it *burns* with a bright flame (from which carbon in form of soot is deposited on a cold surface), forming CO_2 and H_2O . It will explode when mixed with air and ignited. It will not support combustion. If mixed with an equal volume of chlorine gas, the two combine, forming an oily liquid, $\text{C}_2\text{H}_4\text{Cl}_2$. It is from this liquid that the name "olefiant" was given to the gas.

It will be noted that chlorine can be added to C_2H_4 . Hence it differs from CH_4 in *not being a saturated compound*, the carbon is able to take up other atoms to unite with it.

Acetylene, C_2H_2 , like ethylene, is one of the constituents of coal-gas. It has lately come into general use for illuminating purposes, where ordinary coal-gas is not to be had. This is owing to the fact that an extremely simple method of preparing it has been discovered, namely, allowing *water to act gradually on carbide of calcium*. This may be done in a flask in the laboratory, allowing the water to drop slowly on to the carbide, the reaction being



Water and Calcium carbide give Slaked lime and Acetylene.

The gas which comes off will be found to be *colourless* and to have a *sickly smell*. It is *poisonous* when undiluted. It burns with a bright smoky flame, forming H_2O and CO_2 . It *dissolves partly in water*, but nevertheless may be collected in the pneumatic trough in the ordinary way.

Formerly acetylene was prepared by the direct union of carbon and hydrogen, and as the process was a difficult one the gas had no practical value.

SULPHUR.

Sulphur is one of the few elements that are found native. It occurs *in volcanic districts*, and in former times was entirely

derived from this source, though nowadays it is manufactured from its compounds as well.

Heat in a hard tube a common sulphide, such as *iron pyrites* (well powdered). Sulphur forms as a yellowish powder on the cool end of the tube. This yellowish powder is known as **flour of sulphur**; when it is heated, it melts and becomes liquid. The liquid can be cast into sticks, which are known as **roll sulphur** or **brimstone**, the common form in which sulphur is sold commercially. Take some of the brimstone, split it up into small fragments, put some in a flask, and heat gently. It will be found that the sulphur becomes quite liquid at about 115° C.; after this point it becomes thicker, and darkens in colour, and at length is so viscid that the flask can be inverted without the spilling of the sulphur. Sulphur boils at about 440° , giving off a reddish gas. When boiling, some of it should be poured into an earthen crucible, and some of it into perfectly cold water. The latter portion will assume what is known as the **plastic** form: though this is only a temporary condition. The former portion which was placed in the crucible may be compared with the original, and will be found to be the same substance, quite unaltered by the high temperature to which it has been heated.

Sulphur is *dimorphous*, that is, it exists in two crystalline forms, one of which is easily obtained by dissolving a small quantity of brimstone in carbon disulphide and allowing the liquid to evaporate, when we obtain *octahedral crystals*. The other variety, long *needle-shaped prisms*, may be seen by heating a crucible full of sulphur, allowing it to cool and form a crust over the surface, and then pouring out the liquid contents through a hole in the crust. The interior will contain these crystals.

Milk of sulphur is a finely divided powder obtained by boiling together ordinary sulphur and milk of lime.

Sulphur is often precipitated from solutions in the form of a *whitish-yellow precipitate*, as, for example, when sulphuretted hydrogen gas is passed into nitric acid, or when a strong acid is added to an alkaline sulphide.

Sulphur is found in nature combined with many metals as **sulphides**. Of these the most common are pyrites or iron

sulphide, FeS_2 , blende or zinc sulphide, ZnS , and galena or lead sulphide, PbS .

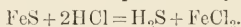
The metallic sulphides are extensively extracted from the earth, and used in the preparation of the various metals. Thus cinnabar or vermilion, which is a sulphide of mercury, is used for the manufacture of mercury. Sulphur unites directly with metals to form sulphides.

Experiment.—Heat some sulphur in an ignition tube, and drop into it either copper turnings or iron filings. Combination takes place at once, and we get copper sulphide or iron sulphide formed.

One of the most important sulphides is **hydrogen sulphide** or **sulphuretted hydrogen**, H_2S , a naturally occurring gas, which is found dissolved in various mineral waters, such as those of Harrogate.

It is largely used in the processes of chemical analysis, as it enables the metals to be separated into different groups.

Experiments.—1. Prepare some sulphuretted hydrogen gas by acting on iron sulphide, FeS , either with sulphuric or hydrochloric acid, thus—



Collect several jars full of the gas. This may be done over water, in spite of the fact that the gas is largely soluble in water.

2. Note that the gas is *colourless*; that it has a *disagreeable smell of rotten eggs*; that it *will burn*, producing either sulphur and water, or SO_2 and H_2O , according to the amount of oxygen which has access to the flame. Observe that when it dissolves in water, the solution is *acid* to litmus (hence its alternative name *hydrosulphuric acid*); that it blackens filter paper, which has been moistened with a solution of lead acetate or silver nitrate, forming black sulphides of those metals. Allow some of the solution to stand for a day or two, it turns milky owing to the sulphur depositing out consequent on the oxidation of the hydrogen of the H_2S .

Note finally that the gas can be poured downwards, therefore it is *heavier than air*, and that if it be mixed with chlorine gas it is decomposed, yielding hydrochloric acid and free sulphur.

3. Make up solutions of bismuth nitrate, copper sulphate, iron sulphate, zinc sulphate, calcium sulphate, magnesium sulphate, and sodium sulphate, and add a little HCl to each. Pass bubbles of sulphuretted hydrogen through each, and note that—

(a) Bismuth and copper salts give immediate precipitates (black);

(b) Iron and zinc salts give no precipitate until a little ammonia be added;

- (c) That salts of calcium, magnesium, and sodium give no precipitate under any circumstances.

Thus it will be understood how sulphuretted hydrogen is used for classing the metals into three distinct groups—

- (a) Those which give precipitates from acid solutions.
 (b) Those precipitated from alkaline solutions.
 (c) Those not precipitated at all.

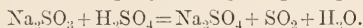
Carbon Disulphide, CS_2 , a liquid several times mentioned in previous pages for its solvent powers, is made by passing sulphur vapour over red-hot charcoal. It is very inflammable and has an unpleasant smell.

OXIDES OF SULPHUR.

We have already seen, that when sulphur is burnt in oxygen or air, **sulphur dioxide, SO_2 ,** is formed.

Experiments.—1. Prepare some sulphur dioxide by a different method, viz., by the action of sulphuric acid on either copper turnings or sodium sulphite. It may be prepared in a flask, and the gas may be collected in jars by displacement of air, and some of it may be passed into water, in which it is soluble, for further experiments.

The reactions are—



2. Note that the gas in the jars is *colourless, acid to litmus*, has a *strong smell* (of burnt sulphur), will *neither burn nor support combustion*, and will destroy the colour of a flower (such as a rose or violet) held in it. It has *bleaching* properties.

3. The solution of the gas in water is known as **sulphurous acid, H_2SO_3 ,** and when it acts on bases it forms salts called **sulphites**. Add some of the solution to caustic potash, or sodium carbonate solutions, or pass the gas into them directly.

On evaporating down, it will be found that potassium sulphite, or sodium sulphite is formed, from which the SO_2 gas can be easily liberated by the addition of a few drops of strong sulphuric acid.

4. If a little Condy's fluid be added to sulphurous acid, the colour is destroyed. This is because sulphurous acid is a *reducing* agent. It subtracts oxygen from bodies, and becomes H_2SO_4 , sulphuric acid. This is further seen when a little nitric acid is dropped into a jar of SO_2 gas; sulphuric acid is formed by the deoxidising of the nitric acid.

It is owing to this property that sulphur dioxide gas is so largely used for *disinfecting purposes*.

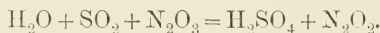
5. To the sulphurous acid solution add—

- (a) Some barium chloride, note the white precipitate soluble in hydrochloric acid,
- (b) Some silver nitrate, and note the white precipitate turning dark.

Compare these reactions of sulphites with those of sulphates later on, and see how the two are distinguished from each other.

Sulphur Trioxide, SO_3 , is another of the oxides of sulphur. It does not occur naturally, and is somewhat difficult to prepare. It is only mentioned here, because, with water, it forms H_2SO_4 , **sulphuric acid**, one of the most important of acids, thousands of tons of which are made every week in this country alone.

The manufacture of the acid on a large scale is dependent on what was mentioned in connection with sulphurous acid, viz., that the last-named acid can be made to take up another atom of oxygen, and thus be converted into sulphuric acid. This is effected by means of one of the oxides of nitrogen, thus—



On the addition of air the N_2O_2 becomes N_2O_3 again, and is once more ready to yield up an atom of oxygen to a fresh portion of the H_2SO_3 .

The process is carried on in large leaden chambers into which *steam, sulphur dioxide, air, and the fumes from heated nitre* are all passed. Sulphuric acid collects as a heavy oily liquid on the floor of the chambers.

Experiments.—1. Prepare a little sulphuric acid by distilling in a retort some green ferrous sulphate. If the vapours which come off are cooled in a condenser, a little weak (and impure) sulphuric acid will be obtained.

A better way is to pass into one large glass vessel the following gases, SO_2 , H_2O , N_2O_4 , and air. The large vessel should occupy a central position, and the smaller flasks in which each of the above gases is generated can be grouped around it. The gases should be passed into the large vessel simultaneously, and the vessel should be provided with a cork with five perforations to admit the glass tube from each of the smaller flasks. The acid thus prepared may be compared with the acid in the laboratory by the following reactions.

2. Compare the weights of equal quantities of water and sulphuric

acid. It will be found that the *pure acid is nearly twice as heavy as water*. Pour some of the acid very carefully into water, and notice the *rise of temperature as the liquids mix*. It may be dangerous to pour a light liquid, such as water, into a heavy liquid, such as sulphuric acid, when the temperature rises in this way; therefore acids are always poured into water, and *water is never poured into acids*.

Heat a little strong acid, notice that the *boiling point is very much higher than that of water*, and, that when it boils, the acid is partly decomposed. Leave out in a beaker about 50 cubic centimetres of strong acid of which you know the exact weight. Re-weigh after two or three days have elapsed. The acid will now weigh much more as it has *absorbed moisture* from the air. For this reason it is used for drying purposes.

Note that a slip of wood plunged into it *chars at once*, because the acid takes away the water from the wood, and leaves the carbon. Write with a piece of wood on filter paper, using *weak* acid instead of ink. Dry the paper over the flame, and notice again how the writing chars.

Sulphuric acid destroys organic matter by abstracting from it the elements of water.

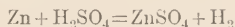
3. Sulphuric acid reacts with many metals and bases forming salts called **sulphates**.

Into a little dilute acid in a test-tube put a piece of zinc, and note that hydrogen gas is given off. When the metal has entirely dissolved, add water, and evaporate down slowly. The whitish residue left is **sulphate of zinc**.

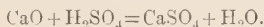
Repeat the experiment with magnesium and iron, and obtain in the same way the sulphates of these metals.

Note that *with these metals hydrogen is given off, and sulphates of the metal formed*. Now try the same experiment with mercury and copper. This time we do not get hydrogen, but *sulphur dioxide and sulphate of the metal*.

The reactions are—



Sulphuric acid acts in the same way on the oxides and hydrates of the metals forming sulphates and water. Try its action on the following: caustic potash, quicklime, copper oxide, ammonium hydrate. Obtain the sulphate in each case by evaporation, and write out reactions thus—



Many of the sulphates are found in the earth's crust. We have seen that calcium sulphate, or gypsum, is the cause of the permanent hardness of water. The same substance occurs as **alabaster**, the well-known ornamental building stone, also as **selenite**,

Barium sulphate, or **heavy spar**, is another common sulphate. The sulphates of aluminium, magnesium, and copper are likewise found in the earth.

When sulphides such as iron pyrites are exposed for any length of time to the oxidising action of moist air, they are slowly converted into sulphates.

The *sulphates are on the whole soluble salts*; barium and lead sulphates are, however, insoluble.

It has been found that, in the case of some metals such as potassium and sodium, there are *two distinct kinds of sulphates*, one containing hydrogen, and the other containing metal and acid only. We know that the composition of sulphuric acid is represented by the formula H_2SO_4 , therefore the formula of the two potassium sulphates must be KHSO_4 and K_2SO_4 .

As a matter of fact, we are actually enabled to demonstrate this point experimentally and replace the hydrogen in an acid bit by bit, or rather *atom by atom*, putting an atom of metal in the place of each atom of hydrogen. The **basicity of an acid** depends on the *amount of replaceable hydrogen* which the acid contains. For this reason H_2SO_4 is said to be **dibasic**, that is, it contains two atoms of replaceable hydrogen. It will be remembered that H_2CO_3 , carbonic acid, is also dibasic. Of **monobasic** acids nitric acid, HNO_3 , and hydrochloric acid, HCl , may be taken as types, while ortho-phosphoric acid, H_3PO_4 , may serve as an example of a **tribasic** acid with three replaceable atoms of hydrogen. Acids are sometimes defined as "**compounds of hydrogen with some acid radicle.**" This latter may be either an element, as in such acids as H_2S , HCl , HBr , or it may consist of a group of atoms such as SO_4 , in sulphuric acid, and NO_3 , in nitric acid.

The **acid radicle**, such as SO_4 , is that part of the acid which is *constant* or unchanged in the action of the acid on various metals and bases. The hydrogen is the *removeable part*, and for it we may substitute, both theoretically and practically, almost any metal.

Thus, starting with H_2SO_4 and continually substituting some

metal for the hydrogen, we get a series of sulphates, for instance—

Hydrogen sulphate,	H_2SO_4 .
Potassium hydrogen sulphate,	KHSO_4 .
Normal potassium sulphate,	K_2SO_4 .
Calcium sulphate,	CaSO_4 .
Ferrie sulphate,	$\text{Fe}_2(\text{SO}_4)_3$.

The sulphates which are mostly soluble salts are distinguished by the following tests:—

- (1) With barium chloride they give a *white precipitate insoluble in hydrochloric acid*.
- (2) With lead nitrate they give a *white precipitate, soluble in caustic soda*.

PHOSPHORUS AND ITS MORE COMMON COMPOUNDS.

Phosphorus, like carbon, hydrogen, oxygen, nitrogen, and sulphur, is one of the constituents of both animal and vegetable matter, and is therefore one of the widely distributed elements. Unlike the above elements, however, it is not found free, owing to the fact that it oxidises very easily.

Animals obtain their phosphorus from plants, and plants obtain it from the soil in the form of phosphates. Phosphorus is used by animals for the formation of bones which consist chiefly of *phosphate of calcium*, $\text{Ca}_3(\text{PO}_4)_2$. It is from bones that we obtain the element phosphorus, by a somewhat lengthy process, which cannot well be carried out in the laboratory. It consists mainly in treating *bone ash with sulphuric acid* and thus getting rid of some of the calcium in the form of calcium sulphate. When this has been subtracted, the remaining solution is evaporated down, and raised to a high temperature together with powdered charcoal. Phosphorus distils over and is collected under water. It is in appearance a *yellow waxy substance, which must be kept in water, as it oxidises easily in the air*.

Experiments.—1. Cut off some pieces of yellow phosphorus, under water; expose one of these pieces to the air and notice the *white fumes of oxide of phosphorus* which at once come off. In the dark these fumes are luminous, and phosphorus, when oxidising, gives out a **phosphorescent light** of a pale greenish-yellow colour. If the phosphorus be touched with

a warm glass, or copper rod, it will at once burst into flames giving off dense fumes of phosphorus pentoxide, P_2O_5 .

2. Place one of the pieces of phosphorus in a deflagrating spoon, light it, and burn it in a gas jar of air. Shake up the *white* fumes of P_2O_5 with water, and note that they *dissolve*, forming *phosphoric acid* (test with litmus).

3. *Dissolve* one of the fragments of phosphorus in a little *carbon disulphide* and place on a watch-glass. As the CS_2 evaporates, the phosphorus will catch fire spontaneously. Phosphorus *dissolves* also in *ether*.

4. If one or two pieces of yellow phosphorus be heated in a vessel containing nothing but carbon dioxide, or nitrogen, a gradual change in appearance will be noted until finally nothing is left but a red powder. This is known as **amorphous** or **red phosphorus**, and is an *allotropic form* of that element.

5. Examine the red phosphorus, and note that *it does not oxidise* and give off fumes easily as does the yellow : for this reason it need not be kept under water. Note that it is *not luminous* in the dark.

It can be reconverted into the yellow waxy variety by heating it in a hard glass tube away from the air.

Yellow phosphorus, which is used for ordinary wax matches, is extremely poisonous, but the red variety, which is put on the boxes of the "*Safety matches*," is not so.

Oxides of Phosphorus.—There are two oxides of phosphorus ; the lower one is called **phosphorous anhydride**, and has composition P_4O_6 . It is formed when phosphorus *oxidises slowly in a limited supply of air*. It is a white solid which dissolves in water, forming **phosphorous acid**, H_3PO_3 . This acid combines with metallic bases, forming salts called **phosphites**.

(*Note.*—Compare sulphur dioxide, SO_2 (sulphurous anhydride), which forms H_2SO_3 , sulphurous acid, and in turn gives rise to salts called sulphites).

Phosphorus pentoxide, or phosphoric anhydride, has the composition P_2O_5 . As already noted, it is a white finely divided solid which is formed when phosphorus oxidises in a good supply of air or in oxygen. It combines eagerly with water to form **phosphoric acid**. Its affinity for water is so great that it is used as a **dehydrating agent**. There are three phosphoric acids which differ from each other by the *amount of water they contain*, thus—

Ortho-phosphoric acid, H_3PO_4 , is formed from $P_2O_5 + 3H_2O$.

Pyro-phosphoric acid, $H_4P_2O_7$, is formed from $P_2O_5 + 2H_2O$.

Meta-phosphoric acid, HPO_3 , is formed from $P_2O_5 + H_2O$.

All of them form salts called **phosphates**. Ortho-phosphoric acid, being tribasic, forms three classes of salts with metals of the alkalis, such as potassium and sodium, thus—

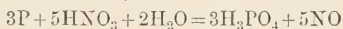
H_3PO_4 , Tri-hydrogen phosphate.

NaH_2PO_4 , Sodium di-hydrogen phosphate.

Na_2HPO_4 , Di-sodium hydrogen phosphate.

Na_3PO_4 , Tri-sodium phosphate.

Experiments.—Warm gently in a test-tube some small pieces of phosphorus and some dilute nitric acid. The phosphorus gradually disappears, being oxidised by the nitric acid, thus—



Phosphorus and Nitric acid and Water yield Phosphoric acid and Nitrogen dioxide.

The liquid left may be partially evaporated down, and will be **ortho-phosphoric acid**, as may be proved by adding to it—

(a) Silver nitrate, which will give a yellow precipitate of *silver ortho-phosphate*.

(b) Ammonium molybdate, which will, when a little nitric acid is added, give a yellow precipitate.

If the ortho-phosphoric acid be heated, until much water is driven off, it will eventually become a *transparent, colourless, solid mass*. This is *glacial* or **metaphosphoric acid**.

(a) Silver nitrate gives a white precipitate with metaphosphates.

(b) Albumen is coagulated by metaphosphates.

Thus it is easy to distinguish between ortho- and meta- phosphates.

PHOSPHORETTED HYDROGEN, PH_3 .

Just as sulphur and hydrogen combine to form H_2S , so does phosphorus unite with hydrogen to form **phosphine**, PH_3 .

It is prepared by warming together caustic potash solution and small pieces of yellow phosphorus in a flask or retort, from which all air has been displaced by coal-gas.

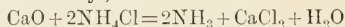
The experiment had better not be done by any but advanced students, as, when the phosphoretted hydrogen comes off, it is often mixed with small quantities of another hydride, PH_2 , which renders the mixture of gases spontaneously inflammable in air, and consequently liable to explode. Phosphoretted hydrogen is an *invisible gas* with a *disagreeable smell* of bad fish: *it burns*, forming P_2O_5 and water. It is not of use or importance, as H_2S is, in the laboratory.

COMPOUNDS OF NITROGEN WITH HYDROGEN AND OXYGEN.

Ammonia, NH_3 , is one of the most important of the few compounds that nitrogen forms with other elements. Although it can be prepared *synthetically* by the direct union of nitrogen and hydrogen, when the gases are subjected to a silent electric discharge, the actual source of ammonia and all its compounds is coal, or rather the "*ammoniacal liquor*" which distils out from coal. This liquor, when heated with lime, gives off ammonia gas, which is converted either into chloride or sulphate of ammonium by the addition of hydrochloric or sulphuric acid, and is sold in the form of one of these salts.

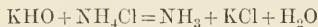
Ammonia gas is best prepared experimentally as follows :—

1. Heat together, in a dry tube, quicklime and sal-ammoniac (chloride of ammonium): NH_3 gas comes off, and may be collected either by upward displacement or over mercury; the reaction is—



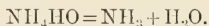
Lime and Sal-ammoniac give Ammonia, Calcium chloride, and Water.

2. Any *ammonium compound*, when heated with a *caustic alkali*, gives off ammonia gas. Thus, if instead of lime in the last experiment we used caustic soda or caustic potash, we get a similar reaction—



Caustic } + Sal-ammoniac yield Ammonia gas + Potassium chloride +
potash } Water.

3. If quantities of ammonia gas be required in the laboratory for any particular purpose, the simpler way of obtaining it is to warm gently some strong ammonium hydrate, thus—



In order to study the properties of ammonia, prepare by any, or all, of the above methods some jars of ammonia gas and perform the following experiments :—

1. The gas is *lighter than air*, and can be poured or collected upwards. It affords a convenient illustration of diffusion, for if one of the jars of NH_3 be inverted over a similar jar full of air, in spite of the fact that the NH_3 is the lighter gas, enough of it will diffuse downwards to make a piece of moistened red litmus paper blue.

2. It is *strongly alkaline*. Red litmus at once becomes blue in the gas, or its solution in water. It *turns yellow turmeric paper brownish-red*. If a rod dipped in hydrochloric acid be held in the gas, dense white fumes of *ammonium chloride* are formed.

These are three characteristic tests for ammonia gas.

3. It is *extremely soluble in water*, for, if one of the jars of pure dry ammonia be placed in a basin of water, the water will quickly rise to the top of the jar. As a matter of fact water will absorb 1150 *times its own volume of ammonia*, the resulting product being known as NH_4HO , or **ammonium hydrate**. This liquid is lighter than water, having a density of '880.

4. Notice that the gas is *colourless*, that it has a *strong and characteristic smell*, and a *caustic taste*. It *will burn*, as long as a flame is in contact with it, and a supply of oxygen is given to it. It *will not support combustion*.

5. *At a red heat it is decomposed* into three volumes of hydrogen and one volume of nitrogen. Electric sparks also decompose it into its constituents, and chlorine gas decomposes it, combining with the hydrogen and setting free the nitrogen.

ALKALIES AND BASES.

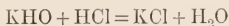
Ammonium hydrate, obtained by the solution of ammonia gas in water, strongly resembles the **true alkalies, caustic soda and caustic potash**. These bodies, which are termed **alkalies**, are **hydrates or hydroxides** of the metals potassium and sodium. They may be regarded as water, in which one atom of hydrogen has been replaced by metal, thus— HHO ; KHO ; NaHO ; and in the case of ammonia the atom of hydrogen is replaced by the compound radicle NH_4 , forming NH_4HO . There are others of this class ; for example, slaked lime $\text{Ca}(\text{OH})_2$, or calcium hydrate, is derived from two molecules of water in which the calcium replaces two of the hydrogen atoms. All metallic hydrates are termed **bases**, but the alkalies possess *basic properties* in a more marked degree than the others.

Experiments.—1. Take solutions of ammonium hydrate, caustic soda, caustic potash, and calcium hydrate.

Test each with *reddened litmus paper*, they will *all turn it blue*.

All these solutions have a *soapy* feel and taste.

2. Neutralise each of the solutions with nitric and hydrochloric acids, and, when the resulting mixture affects neither kind of litmus, evaporate down, and obtain the salt formed ; write out reactions thus—



Caustic potash + Hydrochloric acid give Potassium chloride and Water.

Note that in each case *the alkali neutralises the acid*, and the result is the formation of a **salt** and *water*.

3. Show that a similar result is obtained by using other bases, such as the hydrates of aluminium, magnesium, and calcium: note that *in each case the metal replaces the hydrogen in the acid, a salt is formed, and that water is the other product of the experiment.*

4. Modify experiment 2. above, and *ascertain the quantities of each of the alkalis, soda, potash, and ammonia, which will neutralise equal quantities of the two named acids.* This may be done as follows:—

Dissolve 5 grams of caustic potash in 250 cubic centimetres of water. Put 50 cubic centimetres of this solution into a beaker, and allow hydrochloric acid (mixed also in above proportion) to drop into it from a burette till the solution is exactly neutral.

Repeat this some three times, and take the mean as the true amount.

Having found out the amount of hydrochloric acid which neutralises caustic potash, ascertain the quantities of the other two alkalis required to neutralise the same amount of hydrochloric acid. They will be in the same ratio as their molecular weights.

Then find out the amounts for equal quantities of nitric acid.

NOMENCLATURE OF SALTS.

Seeing that **salts are compounds of acids and bases**, a system of naming acids and salts was devised, which would show the relationship existing between them.

Thus if the acid ended in the suffix **-ous**, the salt would have the suffix **-ite**. If the acid ended in **-ic**, the corresponding salt would have the termination **-ate**. Examples: **nitrous** acid forms **nitrites**, but **nitric** acid forms **nitrates**.

Unfortunately, this simple system is complicated by the prevalence of older and misleading names: for acids such as hydrochloric acid and hydrosulphuric form *chlorides* and *sulphides*.

If the following table, which gives the acids (and salts) of nitrogen, chlorine, and phosphorus, be carefully studied, the system of nomenclature will be understood more readily:—

ACID.		SALTS.
HCl	hydro-chloric	chlorides.
HClO	<i>hypo-chlorous</i>	<i>hypo-chlorites.</i>
HClO ₂	chlorous	chlorites.
HClO ₃	chloric	chlorates.
HClO ₄	<i>per-chloric</i>	<i>per-chlorates.</i>

	ACID.	SALTS.
HNO	<i>hypo-nitrous</i>	<i>hypo-nitriles.</i>
HNO ₂	<i>nitrous</i>	<i>nitriles.</i>
HNO ₃	<i>nitric</i>	<i>nitrates.</i>
H ₃ PO ₂	<i>hypo-phosphorous</i>	<i>hypo-phosphites.</i>
H ₃ PO ₃	<i>phosphorous</i>	<i>phosphites.</i>
H ₃ PO ₄	<i>phosphoric</i>	<i>phosphates.</i>

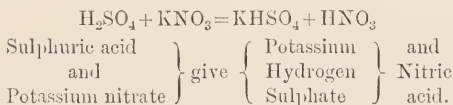
From this it will be seen, that the addition of one atom of oxygen, in each case, constitutes the main difference in the acids and their salts.

The lowest acid is distinguished by prefix **hypo** and suffix **-ous**, the next acid by the suffix **-ous** only, the next by suffix **-ic**, and the highest by the prefix **per-** and the suffix **-ic**.

Hydrogen nitrate, nitric acid, HNO₃, is the other important compound which nitrogen makes with oxygen and hydrogen. Under the name *aqua fortis* it has been known commercially for a long time.

It is now used in large quantities for the manufacture of high explosives, such as gun-cotton, dynamite, nitro-glycerine, and picric acid. The large percentage of oxygen it contains, and the ease with which it gives this up, renders it peculiarly suitable for the purpose.

Experiments.—1. Prepare some nitric acid by distilling in a retort a mixture of saltpetre and strong sulphuric acid. The gas which comes over will condense into a yellowish liquid in the receiver ; the reaction is—



Any other nitrate will do just as well. Try smaller quantities of sodium nitrate, strontium, lead, or barium nitrates ; all of them salts commonly found in laboratories.

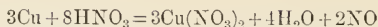
2. Apply the following tests to the nitric acid you have prepared.

Add some of it to indigo solution and note the *bleaching action*.

Observe that it is *strongly acid to litmus*.

Into separate test-tubes put small quantities of metallic lead, copper, and bismuth. Warm each with a little of your nitric acid. The *metals dissolve, nitrates are formed*, and the characteristic brown fumes of nitrogen peroxide are evolved.

The action is—



Copper and Nitric } give { Copper and Water } Nitric
acid } { nitrate and } oxide.

Nitric oxide is really a colourless gas, but, directly it gets into the air, it combines with oxygen, forming brown fumes of NO_2 . Prepare these nitrates (and others), by evaporating down slowly the liquid left when the metal has entirely disappeared, and the action ceased.

Write out equations, as above, in each case, and calculate the amount of acid required to dissolve 25 grams of each of the metals.

Note that hydrogen is never one of the final products of the action of nitric acid on a metal.

3. Warm together in a test-tube some nitric acid and scraps of tin. Observe that tin oxide, a white powder, is formed, and nitrogen peroxide is evolved. This experiment and the following ones show the *strong oxidising properties* of nitric acid.

Treat in the same way small pieces of sulphur, and in another test-tube fragments of phosphorus. Both elements are oxidised, and sulphuric and phosphoric acids produced. (Test for each in the liquids left.)

The way to *test for nitric acid* and the nitrates is as follows:—

Add to a little nitric acid (or solid nitrate of any kind) a few drops of strong sulphuric acid, cool the mixture, and pour on it a solution of ferrous sulphate (made by dissolving FeSO_4 crystals in cold water). A black ring will form where the two liquids meet each other.

The **nitrates** are an important class of salts. They are *mostly soluble*, but a few, such as the nitrates of bismuth and mercury, have a tendency to form basic salts with water, and do not therefore appear to dissolve readily. When *heated, nitrates are decomposed into oxides*.

Experiments.—Heat in a crucible some blue copper nitrate. Note that it gets off a brown gas, and is converted into black oxide of copper.

Repeat the experiment, using potassium nitrate instead. After it has fused, and turned into a white mass, apply to it the test given above for nitrates, and see that it will no longer answer to this test.

Nitrates are strong oxidising agents, and for this reason potassium nitrate, KNO_3 , is used for making gunpowder, which consists of 75 per cent. nitre, 10 per cent. sulphur, and 15 per cent. charcoal.

Nitrous acid, HNO_2 , is made by the solution of N_2O_3 gas in water. It forms salts called **nitrites**.

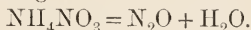
Potassium nitrite is formed when potassium nitrate is gently heated. Other nitrites may be similarly prepared.

OTHER COMPOUNDS OF NITROGEN.

There are five oxides of nitrogen ; they are—

1. Nitrogen *mon*-oxide, N_2O , nitrous oxide, laughing-gas, or hypo-nitrous anhydride.

It is made by heating ammonium nitrate thus—



It is used as an anæsthetic by dentists.

2. Nitrogen *di*-oxide, N_2O_2 , or nitric oxide, made, as mentioned above, by action of nitric acid on copper.

3. Nitrogen *tri*-oxide, N_2O_3 , or nitrous anhydride, which, with water, gives nitrous acid.

4. Nitrogen *tetro*xide, N_2O_4 , peroxide of nitrogen, the familiar brown gas, formed when nitric acid acts on metals, and the N_2O_2 given off is oxidised.

5. N_2O_5 , nitrogen *pento*xide, or nitric anhydride, which, when dissolved in water, forms nitric acid.

Note in the above the Greek prefixes *mon*-, *di*-, etc., denoting the amount of oxygen contained in each oxide. Note also that each oxide contains one more atom of oxygen than its immediate predecessor.

This series of oxides forms a good illustration of the second law of chemical combination, namely, that—

When an element combines with another in more than one proportion, the higher proportions are invariably multiples of the lowest.

It will be noted that the amount of oxygen in a molecule of the lowest oxide is one atom, or 16 parts by weight, and that the increase is one atom (16 parts by weight) in each case.

CHLORINE AND ITS COMPOUNDS.

Chlorine, a heavy yellow gas with an irritating smell, does not itself occur free in nature, but the chlorides are an important body of salts of wide occurrence.

Common salt, or sodium chloride, is naturally the most important, as being the most widely diffused. Hydrogen chloride, which escapes in large quantities from volcanoes, is likewise of great importance both commercially and in the laboratory.

Chlorine gas can be easily prepared from either of the above chlorides.

Experiments.—Take a flask, put into it a little black oxide of manganese and some strong hydrochloric acid, and warm gently. Chlorine gas comes off at once, and, being heavier than air, may be collected in gas jars by downward displacement. Collect several jars. The reactions which take place are—



Hydrochloric } Manganese } give { Chloride of } and Chlorine + Water.
acid and } oxide }

Chlorine has a *greenish-yellow colour*; a *very irritating smell*; it is *poisonous*; it *does not burn*; it *does dissolve in water*.

Powder up some antimony into fine fragments and drop them into the gas. Notice the sparks showing that the antimony has burnt and formed thick white fumes of *antimony chloride*. *Metals burn in chlorine, forming chlorides*.

Light a taper and plunge it into a jar of the gas; it will burn with a red, smoky flame, because the chlorine *unites with the hydrogen of the wax, forming hydrochloric acid*, and carbon is set free because *chlorine takes its place in the compound*. A similar reaction occurs with chlorine gas in water: in a few days hydrochloric acid will be formed in the solution, and this can only have been formed by the combination of the chlorine with the hydrogen of the water and the consequent *liberation of oxygen*.

Chlorine and hydrogen gases, when mixed in equal volumes and exposed to light, combine spontaneously and form hydrochloric acid gas.

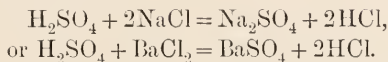
Owing to the fact that it unites eagerly with hydrogen, chlorine is an *oxidising agent* in the presence of water, from which it sets free oxygen. Observe this in the *bleaching* power of chlorine. Place in a jar of the gas some wet red blotting paper and some wet litmus paper. They are *bleached white by oxidation*. Compare this with bleaching action of sulphur dioxide, which bleaches by *reduction*, *i.e.* taking away oxygen from other bodies.

For bleaching purposes on a large scale chlorine is used in the shape of "**bleaching powder**," which is a mixture of the hypochlorite and chloride of calcium.

It is easily made by passing a stream of chlorine gas into a flask containing slaked lime.

To test its bleaching properties, dip some litmus paper into any very weak acid and then into a solution of bleaching powder. The acid liberates the chlorine, and the litmus is at once bleached.

Hydrogen chloride, Hydrochloric acid, HCl, was formerly called "*muriatic acid*," or "*spirit of salt*." It is prepared by the action of sulphuric acid on common salt and most other chlorides, thus—



Experiments.—By either of the above methods prepare some HCl gas, and as it comes out of the flask lead it into a beaker of cold water, in which it will be found to dissolve easily. When the water is saturated with the gas it forms a strong solution of hydrochloric acid: in fact over 30 per cent. of the total weight of the solution is hydrochloric acid.

Add to some of it silver nitrate; note the white precipitate of silver chloride soluble in ammonia. This is the characteristic test for soluble chlorides.

Put some of the solution in a test-tube and warm it with MnO_2 : the chlorine comes off at once. To another portion in a test-tube add some lead acetate, or nitrate, solution: a white precipitate of lead chloride is formed.

Put some of the solution into the two-tubed voltameter (with carbon electrodes), and pass a current of electricity through it. It splits up into equal volumes of hydrogen and chlorine. Try the action of some of the acid on pieces of zinc and magnesium. Note that hydrogen is evolved and chlorides of the metals formed. Neutralise some with ammonia, and obtain the sal-ammoniae by evaporation.

Mixed with nitric acid (in the proportion of 4 HCl to 1 HNO_3) it is known as "**aqua regia**," and it is used as a solvent for the noble metals, gold, platinum, etc.

VALENCY AND EQUIVALENT WEIGHT.

The hydrogen in the molecule of hydrochloric acid has been experimentally proved to be indivisible. The same may be said of the chlorine. It is, therefore, evident that one atom of chlorine (weighing 35) combines with one atom of hydrogen (weighing 1) to form hydrochloric acid. In the same way every molecule of common salt is made up of one atom of sodium ($\text{Na}=23$) and one atom of chlorine ($\text{Cl}=35$), and from this it is fair to argue, that, if sodium and hydrogen combined, the compound particles would be formed of one atom of each.

Elements which combine with hydrogen (or chlorine), in the

proportion of one atom to one atom, are said to be **monovalent** or **monads**.

Valency, in short, means the **chemical worth** of an element, an atom of hydrogen being taken as the standard. The principal *monovalent* elements are hydrogen, chlorine, bromine, iodine, potassium, sodium, ammonium (compound radicle NH_4), silver. Each of these unites with others of the same valency in the proportion of one atom to one atom; thus KCl , KBr , NH_4Cl , NaBr , HI , HBr , etc., are the formulæ of several of the compounds.

Divalent atoms unite with two atoms of hydrogen (or other monad element). Examples of **dyad** elements are oxygen, sulphur (in some of its compounds), calcium, barium, copper, zinc.

Examples of their compounds, H_2O , H_2S , CaCl_2 , etc.

Trivalent atoms unite with three atoms of monad elements.

Examples of **triads**, nitrogen, boron, phosphorus, arsenic, etc.

Examples of their compounds, NH_3 , PCl_3 , etc.

(*Note*.—It requires three atoms of a divalent element to combine with two atoms of a triad, *e.g.*, As_2O_3 .)

Tetravalent atoms are tin, carbon, and silicon. Examples, CH_4 , SnO_2 .

Although one atom of any monovalent element combines with one atom of hydrogen, **the actual weight of each element which is equivalent to one of hydrogen varies**. Thus in HCl the weight of chlorine equivalent to one part of hydrogen is 35; and in the same way the weight of silver (deduced from compound AgCl) equivalent to one part of H is 108, whilst sodium has an equivalent weight of 23.

The **equivalent weight of an element** is, then, the amount (by weight) of that element which is equivalent to one part (by weight) of hydrogen.

Thus from the composition of ammonia gas, NH_3 , it is plain that the equivalent weight of nitrogen is $\frac{1}{3} \times 14 = 4\frac{2}{3}$.

Care must be taken to *distinguish clearly between valency, and equivalent, and atomic weights*, thus: the atomic weight of oxygen

is 16, its equivalent weight is 8 (deduced from H_2O in which 2 parts by weight of H combine with 16 of O), and it is divalent, or worth 2 atoms of hydrogen.

QUESTIONS AND EXERCISES.

1. How much carbon monoxide and how much carbon dioxide can be obtained from 20 grams of oxalic acid? Compare the physical and chemical properties of the two gases.

2. What do you understand by the law of chemical combination in multiple proportions? Give several examples of the law.

3. What are the materials you would require for making chlorine, and what quantities must be used in order to obtain 1000 grams of this gas?

4. What weight of sulphur is required theoretically to produce 100 tons of sulphuric acid?

5. Charcoal, graphite, and diamond are said to be allotropic modifications of carbon. Explain this statement, and give experimental proof of its truth.

6. Carbon dioxide, hydrochloric acid gas, sulphuretted hydrogen and ammonia gas are passed for some time through separate portions of distilled water. Can they be recognised in the water; if so, how?

7. How many volumes of oxygen are required for the complete combustion of 500 volumes of each of the following gases, and how many volumes of CO_2 will in each case be formed—olefiant gas, acetylene, carbon monoxide?

8. By what experiments would you distinguish ordinary phosphorus from amorphous phosphorus, graphite from iodine, chlorine from ozone, carbon dioxide from nitrogen?

9. How could you prove that chlorine is a constituent of common salt and of hydrochloric acid? Calculate the percentage composition of these two substances.

10. 300 cubic centimetres of a solution of caustic potash, containing 40 grams KHO per litre, are required to neutralise 100 cubic centimetres of sulphuric acid and the same volume of nitric acid. Calculate the amount of each acid in solution.

11. How could you convert sulphur dioxide into sulphuric acid, and sulphuric acid into sulphur dioxide?

12. Classify the following substances as elements and compounds: chalk, graphite, water, brass, sulphur, iron, ammonia, oil of vitriol, diamond, ozone, spirit of salt.

13. Define an acid. Give the general properties of acids and explain what is meant by the "basicity" of an acid.

14. Explain the terms "oxidising" and "reducing" agent. Give some

examples of the oxidising powers of nitric acid and the reducing powers of carbon.

15. Explain the meaning of the statement that the atomic weights of hydrogen, carbon, and oxygen are respectively 1, 12, and 16. What are the equivalent and molecular weights of these elements? Give reasons for your answer.

16. Write out formulæ for any five nitrates, five sulphates, five sulphides, and five chlorides.

17. Write out equations representing the action of sulphuric acid on (a) ferrous sulphide, (b) sodium nitrate, (c) manganese dioxide, (d) copper, (e) zinc.

18. Given some ordinary phosphorus, how would you prepare from it (a) phosphorus pentoxide, (b) common sodium phosphate, (c) phosphoretted hydrogen?

19. If one gram of hydrogen at normal temperature and pressure fills 11,200 cubic centimetres, what weight of iron must be dissolved in acid to procure a cubic metre of hydrogen ($\text{Fe}=56$)?

20. The formula for sulphuric acid implies that the hydrogen in its molecule is divisible in two: what are the reasons for asserting that the hydrogen really can be divided?

21. 500 cubic centimetres of carbon dioxide are passed over incandescent charcoal. What compound is formed, and what volume of it?

22. 150 litres of ammonia gas are confined over mercury, and 80 litres of hydrochloric acid gas are then admitted. What will be the resulting action, and what will be the composition and volume of the remaining gas?

23. What is the relation between the molecular weight and the density of a gaseous compound? Give explanatory examples.

24. What is the equivalent weight of an element? Point out how equivalent weight differs from atomic weight. If the atomic weight of magnesium is 24, what is its equivalent weight, and what its valency?

CHAPTER X

THE MEANING OF ENERGY

CHANGE OF STATE AS RELATED TO TIME AND SPACE AND THE CONCEPTION OF ENERGY

It has been stated already, that bodies displaced equally from the surface of the earth reach it again simultaneously, if allowed to fall freely. In the case of the pendulum, which is now before us for consideration, we have a body so suspended and constrained, that it can only partially fall to the earth. The free fall is checked by the shape and attachment of the body, or, to use more exact terms, by the mode of constraint of the system, but it is checked in a special way, and in accordance with certain definite laws, which are readily discovered by experiment. Although we may not understand the exact nature of the changes taking place during the oscillation of a pendulum, certain aspects of those changes may be noted, and certain facts be demonstrated.

THE RELATION OF TIME OF OSCILLATION TO THE LENGTH OF PENDULUM.

Two heavy bodies suspended by cords or thin wire of different lengths may be first used, to show that the shorter pendulum moves more rapidly than the longer one. Note also that a pendulum, one-half the length of another, makes four oscillations to each one of the other. Also that it moves with sixteen times the rapidity, if it be one-quarter the length of the other. On making further experiments it is always found that *the rate is inversely as the square of the length*. This is a fact of great importance in the behaviour of the pendulum. Moreover, it is also important to recognise that this relation is always maintained. It is constant at all times and in all places.

REASONS FOR ASSUMING THE SWINGS OF THE SAME
PENDULUM TO OCCUPY THE SAME TIME.

The primary condition of making any measurement of time is to be able to decide, *when two quantities of time are equal*. In this the measurement of time resembles all other measurements. On all occasions it is necessary to know, when two quantities are equal, and without that knowledge no measurement is possible. All measurement begins with a determination of the equality of two quantities.

In dealing with time, however, a special difficulty is known to arise. The unit is not, as far as we yet know, a fixed thing. The pendulum itself can be referred to, but at present we are unable to say definitely, that *the swing of the pendulum is constant in value*. It may be asserted that it is so, and we know that all our ideas about time take their start from that belief, but it is a useful exercise to consider the arguments upon which that belief is based. If due thought is given to these remarks, fewer difficulties will be met in the future.

In the first place, there is great probability in the statement, that similar changes under the same conditions will always occupy the same time. This is part of a general belief that *like causes produce like effects*, in fact, a part of the conception of the **uniformity of nature**.

Experiments.—Arrange two pendulums, one twice the length of the other, measuring from the point of suspension to the centre of the “bob.” This may be a piece of metal, weighing 2 or 3 ounces. Fine wire or cord may be used for suspension. They are to be placed one behind the other, so that the relative number of oscillations taking place in the same interval of time may be readily ascertained. A little practice will be needed. Start both swinging at the same instant. The shorter pendulum will swing four times to each swing of the longer one.

Observe that the same relation is maintained on all occasions by the same pendulums. Observe also that the same kind of relation exists between any two pendulums. Take, for example, pendulums of lengths as 2 to 3. The shorter will oscillate nine times to the other four. Two observers will be needed here, unless an indirect mode of observation be employed. The simplest indirect mode depends upon paying attention to successive transits of one pendulum over the other at the centre. It is clear that both

pendulums will be together at their position of rest every now and again. Between any two of these instants when they coincide, one pendulum will have performed a certain number of oscillations, and the other will have performed another number of oscillations, which differs from the former by one. Now these two numbers will be performed in the same space of time. The object, therefore, is to count one set of oscillations between two transits, and the other set will be more or less numerous by one. If six oscillations take place in the period between two transits in the case of the more rapidly moving pendulum, the slower one will execute five.

Observe that two pendulums of the same length keep the same period, though their "bobs" may be of different weights. Care must be taken that the centre of the "bob" in each case is measured from. Observe that ratios are also maintained in the case of unequal lengths, however much the weights are varied.

The prominent fact, which the observations bring to light, is the preservation of ratios as regards time. *There is no doubt, that in a given pendulum we have something which exhibits constancy in its relation to time.*

Greater accuracy in these experiments may be obtained, by employing more careful means of suspension and thereby diminishing friction. A knife-edge, to which a thin wire is fixed for supporting the "bob," and two flat steel plates on a bracket, to support the knife-edge and allow the wire to hang between, bring about a considerable reduction of friction. It will be possible to show with these means, that the period of oscillation of a pendulum is strictly the same, only when the amplitude of vibration is nearly the same. It is only swings of about equal amplitude that are absolutely isochronous.

By a frequent reference to pendulums of various lengths, it is discovered that relative rates of oscillation are always maintained. This fact alone is sufficient foundation for the belief, that the rate of oscillation of any given pendulum is a constant value, or, in other words, that the time taken by successive oscillations is the same. The proof is extended in force, when we find that the constancy is borne out in comparison with any other events, for which equal values in point of time may be surmised, for example, when any given number of oscillations are found to yield the same value as measured by the water-clock. It would be strange if all these varied observations were misleading. Similar values under the same circumstances may be anticipated,

but *constancy of ratio under varied circumstances* points very clearly to the successive values in each case being alike.

It is well to give emphasis at this stage to the fact, *that watches and clocks are of no value in these observations*. In every argument which they are brought forward to illustrate, you may be sure that the question is begged. Their mechanism and their employment involve the truth of that which we are attempting to prove. We cannot prove that a pendulum oscillates in equal periods, nor that the earth rotates in equal periods, by using any kind of chronometer, because *all chronometers are constructed upon the assumption that these two facts are true*.

The use of the pendulum for the purpose of measuring time was first proposed by Galileo, about the middle of the seventeenth century (1641), and, somewhat later, it was independently employed by Huyghens.

But the considerations, which arise from these observations of the beat of a pendulum, bear mainly upon the means of measuring time. There are further items of knowledge, to be gained by attending to certain other features of this important change. We find, for example, that the observation of the state of the pendulum, as regards speed at different points of its path, is a necessary part of our introduction to the conception of energy.

In a long pendulum it is easy to see directly, by watching the lowest part, that movement is most rapid when the pendulum as a whole is vertical. It is, of course, at a minimum, at the moment the pendulum reaches its highest point on either side. There is a gradual acceleration during the constrained fall of the body on each occasion, and during its ascent there is a negative acceleration. In this respect, the swing of the pendulum resembles a combination of two events, that which occurs when a body falls freely to the earth, together with the event of its being forcibly projected upwards. It may be said that the pendulum is so fixed and constrained, that the fall brings about the ascent. But this is not an account likely to give satisfaction. It is comparable in several respects with the fall and rebound of an elastic body from an elastic surface. If grinding and rubbing at

the point of suspension could be entirely obviated, the to-and-fro movement would go on without ceasing, just as certainly as the movement of the earth round the sun is perpetual.

Kinetic Energy.—Every body which is in motion relatively to another differs from it in possessing kinetic energy with regard to this body, though it does not possess any with regard to a body with which it is at rest. And in using this term, **kinetic energy**, it must not be forgotten that it is merely a new aspect of an old fact, namely, *the process of change*. A body in motion is now to be looked upon as something capable of effecting further change, or we may say that we regard a given change in the light of its transformability into other changes. For this reason, the something, energy, of which kinetic energy is one of the forms, is not a new fact of observation. It is merely a *new aspect* of what is already familiar to observation.

Energy is frequently described as *the capacity to do work*, that is, to produce physical change, and the description is useful. But it is advisable to keep in one's mind the thought, that energy is a thing which may present itself *under different forms* or may persist unchanged. One of its most prominent forms is kinetic energy, and this may readily be transformed into something else. The act of transformation is the one irrefutable proof of the existence of an entity quite as real as matter itself.

Illustrations.—Differences between bodies at rest and in motion come too frequently into our daily experience to need description here, and illustrations have been already given. A string which is able to support a heavy body breaks when it attempts to restrain the body in rapid motion as it falls. Allow the body to fall from a higher level, so that it may be checked by the string. The string may be broken. Or again, suspend the body to a spring balance, and note that the extension of the spring varies with the distance of the descent, that is, with the rate at which the body is moving. Or, again, show that a body, attached to a cord passing over a pulley, is able to raise a larger and larger mass tied to the other end of the cord and resting on the floor, as the smaller mass is allowed to fall through a farther and farther distance, that is, the larger mass is displaced in accordance with the speed of the body acting on it. The ballistic pendulum has been employed very suitably to demonstrate the same fact. These and similar occurrences may now be conveniently described as effects of energy, or as illustrations of transformations of energy.

APPLICATION TO THE PENDULUM.

The phenomena of the pendulum are singularly fitted to illustrate the effects of kinetic energy, and the meaning which is to be attributed to the term. It exhibits indeed a transformation of a physical change, in a simple manner, with an almost entire absence of complications, that is, of subordinate changes which tend to obscure the change under investigation. In order to start a pendulum it has first to be moved from its position of rest by an external agency. And this preliminary operation plays an important part in its action. Energy is thereby imparted to the body. Work is performed upon it. Its energy is evident in its subsequent fall. A body does not change unless it is disturbed. The pendulum has gained something in being placed in a position to admit of falling. But it does not simply fall. In virtue of its conformation the fall is followed by an ascent, and, if the pendulum is suspended by employing a knife-edge, a mode in which the least friction occurs, the ascent is equal in distance to the fall. Moreover, the manner of the fall is repeated, though reversed in direction, during the ascent. And this reversal proceeds indefinitely. To describe these changes in the language of energy, we say that *potential energy is given to the pendulum when it is first raised*. This potential energy is converted into kinetic energy during the fall, and the potential energy has entirely disappeared, when the kinetic energy is at its maximum, at the lowest point of the path. During the ascent of the pendulum, the kinetic energy is being gradually reconverted into potential energy, to undergo again the same round in the opposite direction. So long as none of the energy first given to the system escapes in other transformations, this cycle is followed without cessation.

The uniformity of the transformation here described, and the regular progress from a maximum of potential to a maximum of kinetic energy, and *vice versa*, is the distinguishing feature of this event. It is one of the most simple instances of such a change, and it is one in which the theoretical conditions are most completely obtained. But as regards the *actual visible event*, all that

we can see is a body positively accelerating to a maximum and then undergoing a negative acceleration, or retardation, which is succeeded in turn by a positive acceleration. In other words, what is seen is a to-and-fro movement, most rapid in the middle, and null at the limits of the swing. The description given above in terms of energy must not be taken to imply that any further facts are observable.

ENERGY AS RATE OF CHANGE.

It must not be supposed, that we have already learnt all that the pendulum can provide for our instruction. It is possible to gather from the conditions of its movement, that energy is something which impresses itself upon us as *a rate of change*.

The word **rate**, in its ordinary application, bears a meaning which is well understood. When we speak of a rate of motion, we refer to the distance traversed in a known interval. When we compare such rates with one another, all that is needed is to compare the distances traversed in the same interval of time. Rate of motion is the same thing as *speed*.

Rate of growth, again, is the relation of the increment of height or bulk to the time occupied. And rate of change of any kind is the relation or ratio of the added change to the time occupied. But in addition to this more familiar idea of a **time-rate**, the word *rate* may be associated with *space* or *distance*, instead of time, and the two ideas may be held to correspond with one another. We do but transfer our attention from the time, occupied in a given change, to the distance, within which a given event takes place. The ratio of the quantity of change to the distance represents the value of a **space-rate**. An engine, for example, may be said to burn m tons of coal per hour, or to burn n tons per mile. The two expressions illustrate what is meant by the two rates.

The rate at which the pendulum moves increases from zero to its maximum, and it is obvious that the same may be said of its momentum. The rapidity with which momentum is generated during the fall of the pendulum is the same as the rate at which

potential energy is being converted into kinetic energy. The rate of change of momentum is also often described as "the action of a force." And, as we have already learnt, *the action of a force is an instance of energy being transferred from one body to another, or being transformed in character.*

Newton's **Laws of Motion**, which have had so great an influence on the world of thought and have been the foundation of modern science, formed the first systematic and comprehensive statement of the facts of motion. They embrace within their jurisdiction all the known facts about matter in motion, and no other intelligible explanation or description of the facts of our existence, as regards movement, has yet been suggested.

Law 1.—Every body perseveres in its state of rest or of moving uniformly in a straight line, except in so far as it is made to change that state by external forces.

Here we learn what happens to a body which is left to itself. We are told that matter which is left to itself preserves its state, remains as it was, either at rest or moving. This law really helps us to the idea of *inertia*, a term which expresses the incapacity of matter to change of itself. It goes on in the state in which it happens to be.

From this law we obtain our definition of **force**, as that which changes a body's state of rest or of uniform motion.

Law 2.—The change of momentum is proportional to the force, and takes place in the direction in which the force acts.

The first law describes the *inertia* of matter, and the meaning to be given to the word *force*. The second law tells us how force may be measured. It is to be measured by its effects, by the change produced in the quantity of momentum. But Newton's term for force (*Vis Motrix*) includes in its meaning both the intensity of a force and the duration of time during which the force acts. Equal forces are those which produce *equal effects in equal times*. Time must always be taken into account, for the effects of force *accumulate*. They go on increasing as the force continues to act. Hence it is necessary to consider the time during which a given change of momentum has taken place, before

estimating the magnitude of the force producing that change. Note also that change may be an increase or a decrease. Both increased and diminished momentum are indications of the action of force.

The statements made herewith enable us also to decide when two masses are equal. *Equal masses are those in which equal forces, or the same force, produce equal changes of motion in the same time.*

Law 3.—Reaction is equal and opposite to action, that is, the actions of two bodies on one another are always equal and oppositely directed.

If we consider for a moment, that the total quantity of energy in a system of bodies cannot be added to or diminished by any change taking place among themselves, it will be seen that action and reaction must be equal and opposite. The changes in the momenta of two bodies acting on one another must be equal and oppositely directed.

But we have learnt already, that any mutual action between two bodies is called a **stress**. And the word *stress* covers every kind of mutual action in which bodies may be engaged. Hence we may state, that *action and reaction are the two parts which form the whole of stress*, or the two aspects of the same fact, according to the side from which we view the fact.

THE TRANSFORMATION OF ENERGY.

Since the experiments carried out by Rumford in 1798, in which water was boiled by the friction of two metals, it is no longer considered that heat is a fluid. Before that time it was regarded as a material and called **caloric**, but Rumford's demonstration, that an *indefinite quantity* of water could be boiled by the expenditure of sufficient work in rubbing the two bodies together, and, further, that the heat brought into existence was roughly proportional to the work which was performed, made it difficult to admit the existence of this substance, and, indeed, rendered such a belief baseless. The same result was obtained by Davy in 1799. He showed that ice could be melted by rubbing

two pieces together. No caloric was supposed to be present in these bodies, yet the effects of caloric were produced by friction.

It is not assuming too much to say that these experiments show the temperature of a body to be a state not necessarily *dependent upon communication of heat* from another body. A larger view of thermal, kinetic, and other states of matter soon became possible in the light of these discoveries. Meanwhile, in 1843, Joule ascertained the quantity of work corresponding definitely with a given quantity of heat. Not only was this clearly established, it was also proved that the value was constant and invariable. That is, he found that a fixed ratio, which he called **the mechanical equivalent of heat**, always represented the terms on which one form of energy could be converted into another. The simplest description that can be given of the facts observed by Rumford and Davy, lies in the statement, that one form of energy is transformed into another, or that a body which is in a given state may be induced to assume another state, the disappearance of one quality corresponding with the appearance of another. The outcome of Joule's work was to enable us to make this statement more definite, to render it possible to say what quantity of one kind of energy would be equivalent to a given quantity of another kind. The numerical value of the energy in each case would be alike if the same units were used in measurement. *It is merely the description of different kinds of energy in terms of their own special units which disguises the fundamental fact, that the quantity of energy is never changed in spite of its transformations.*

APPLICATIONS OF JOULE'S RESULTS.

Although the instances of conversion of one form of activity into another are too familiar to need description, yet it is well to remember, that even in the most common events the equivalence of successive manifestations of energy is preserved. It may not be apparent to superficial observation, that a heavy train, when pulled up by its break, must exhibit the equivalent of its energy

of motion in the raised temperature of break and wheels and of the fragments rubbed away, or that the body which has fallen to the earth is warmer, in exact proportion to the rate at which it was moving when it touched the earth. Yet if observation were accurate enough, and all the events which are concerned were measured, the equivalence or correspondence in quantity would be found to be as exactly maintained in the commoner occurrences as in those which form the subject of experimental work. And again, in the use of all heat-motors, whether steam, gas, or oil engines, the available portion of the heat, produced by the combustion of various forms of fuel, finds its equivalent, if not wholly in the kinetic energy of the engine, yet in that energy together with what unavoidably leaks away, in the raised temperature of bearings and in unavoidable losses through cooling or compression of parts. The more closely all the changes which occur are taken into account, the more strictly is it found to be true, that *energy changes in form but not in quantity*.

CONSERVATION OF ENERGY.

Inasmuch as the form of energy which disappears is represented by an equivalent quantity of some other form, the *mutable phenomenon*, energy itself, is incapable of being created or destroyed. We have an indication in the examples already quoted of a principle which is believed to be generally true, namely, that of the **conservation** of energy. It is not difficult to admit, that constancy in the total quantity of energy is a simple deduction, if it be true that one form of energy is replaced in every transformation by an equal quantity of another kind. And any trouble that may exist in realising the truth of this statement is diminished in great part, if we are enabled to observe a cycle of such occurrences. For example, when the energy derived from a steam-engine is converted into electricity in motion, and then reproduced in the form of mechanical energy by the agency of an electro-motor, a cycle of changes of this order enables one to understand, that there is something which is fixed and unchanged underneath such varied manifestations.

PERFORMANCE OF WORK.

The rate at which energy is changed is termed **power**. The quantity of energy which is engaged in a transformation is spoken of as the amount of work. The performance of work therefore consists in a transformation of energy. The quantity of work depends on the quantity of energy undergoing the change. The *rate* at which the change takes place indicates the *power*, and inasmuch as the quantity of energy changed, as well as the rate at which it is changed, have to be taken into account, the term *power* must be held to cover both the magnitudes. Power, then, is the rate of doing work, and it is directly proportional to the *quantity* of work, *i.e.* of energy changed, and, at the same time, inversely proportional to the *time* occupied in the performance.

In raising the bob of a pendulum, work is done. The pendulum possesses energy, which has passed to it from the person performing the work. But the moment it is released, the potential energy which its position confers upon it begins to be converted into the kinetic form. When entirely changed into that form (an event which has occurred when it has reached its lowest point, the point at which it rests when it possesses no kinetic energy), the energy, being indestructible, performs work and raises the pendulum to a corresponding height on the other side. Work is done by reason of the kinetic energy being gradually retransformed into potential energy. There is now nothing to keep it in the potential form, no support to keep it in its position of advantage with regard to energy, and as its energy cannot be destroyed it changes again to the kinetic form. The rate at which these changes take place may be measured with regard to time or space. There is a *time-rate* and a *space-rate*, both measurable, and the relation of change of state to time or to space is the origin of our conception of energy. The *alternation* of forms is that which is characteristic in the activity of the pendulum, and that which requires consideration at a later stage. At present we must be content to attribute it to the constant action of the earth.

Other instances of the performance of work, which do not take the form of a cycle of events, that is, which are not reversible,

may be given. Whenever matter is raised from the earth's surface, energy is conferred upon it. It possesses potential energy and a capacity to perform work. A *head of water* affords an illustration. The fall of this water to a lower point may be utilised to perform work. In a similar manner, energy may be imparted to a complex substance, so as to confer upon it *chemical potential energy*. Work may be done while this kind of energy is being transformed. When the transformed matter resumes its original form, the energy originally imparted is restored and may be utilised. It may be in the form of *heat* or of *electricity in motion*. Coal, which has been produced from carbonaceous matter by the aid of the sun's energy at a remote period of the earth's history, affords an important means of doing work as it loses its chemical potential energy. The stored energy of secondary cells (*accumulators*) gives a supply, when needed, of that electrical energy, which previously passed to them from a dynamo in action, and was retained by them in the form of *chemical energy*.

But with regard to these cases and all others, it will be observed that there is no work done, except during a process of *change in the form of energy*. When no such change is occurring, a body or a system may possess energy, and for that reason may be said to have a capacity for work (and this is the most common definition of energy), but the **act of work** is a change in the form of energy.

THE UNIT OF WORK.

The measurement of work is of the highest importance. The practical activity of the world demands to be regulated and apportioned with the closest possible accuracy. And as it is for the practical purposes of the work of the world, and not for abstract ideas about work, that the unit is needed, it has been based upon a familiar fact and a common illustration of work, namely, the raising of matter from the surface of the earth. The practical unit of work is the **foot-pound**, and it is the work done in raising a pound of any kind of matter one foot away from the earth. It will at once occur to anyone who considers the facts of

gravitation, that this quantity of work may vary slightly in different localities. Indeed, it is not strictly constant, though *constant enough for ordinary purposes*. And it may be regarded as sufficiently constant for all heights which come into practical affairs. Hence the fall of 1000 pounds of water from a height of 100 feet would represent 100,000 foot-pounds of work, and the operation of raising it to that height would also need 100,000 foot-pounds.

An agent which can perform 33,000 foot-pounds *per minute* is said to possess a **horse-power**. Power, it will be remembered, is the rate of doing work. James Watt, the engineer, estimated the working capacity of a horse as 33,000 foot-pounds per minute, and used this value as a standard of measurement.

STORAGE OF ENERGY.

The activity of man consists in the performance of work. To the furtherance of this activity all his mechanical contrivances are directed. All his ingenious inventions, machines, and apparatus have for their sole end an enlargement of the quantity of work which he may perform. And, as we know, the performance of work is a change in the form of energy. The work of man aided by his machines consists in the transformation of energy. He is constantly engaged in modifying one kind of energy into another. The energy resident in coal is changed into energy of motion, and we are carried from one part of the earth to another, or material is cut, shaped, or woven to fit our wants in factories and mills, mainly by the agency of coal. But these performances do not take place either in a very simple or in a very direct manner. Energy cannot be readily transformed just in the fashion that we need it, without many precautions being taken and many auxiliaries being employed. Energy exists everywhere and all around us. It is a fixed quantity in the universe, never increased or diminished, but it cannot be always employed, nor can it always be changed at once into the form which we happen to need at the moment. Here is the place for machinery. At this juncture we resort to certain mechanical contrivances to obtain from

them the kind of energy which we want. *Energy is adapted to our needs by machinery*, which absorbs the energy found in nature and changes it into a useful form.

The process of change must be regulated and controlled. It is important that we should be able to get our supply of useful energy when we need it, and be able to regulate it in quantity. And this is just what machines enable us to do. In the first place they prevent the transformation being too sudden. The explosion of gas is an example of a sudden conversion of chemical energy into heat, a useless conversion under ordinary circumstances. But in a gas-engine the explosion is kept under control, regulated and utilised.

The most frequent form in which we need energy is the kinetic form, and this is easily obtained. But the energy of a body being translated is not an easy form of energy to control. It is better to change the energy of translation into that of rotation, as we do in all engines. The kinetic energy of the piston obtained from the thermal energy of the fuel, whether coal or gas, is converted into **energy of rotation**. There are these two important classes of kinetic energy, that of translation and that of rotation, but the most useful class is that of rotation. In the rapid rotation of a flywheel we have kinetic energy, in a form which is easily handed on, by belts and shafting, to long distances from the place where it is generated. A moment's consideration of the state of affairs in a large mill or workshop, with its system of shafting, will show how important it is to have our energy in the rotational form.

THE FLYWHEEL.

A heavy cast-iron wheel provided with a spindle is mounted either on conical bearings or, better, by means of ball bearings. It is supported horizontally or vertically on a strong bracket. The fixing is arranged with a view to allow the energy of a falling body to be transferred to the fly-wheel. The spindle is long enough to allow a considerable length of cord to be wrapped round it. A loop is made at the end of the cord and fixed over a pin in the spindle, in a manner to permit its detachment as the cord is unwound. A weight is now attached to the cord, and it is

raised by fixing the loop on the pin and turning round the flywheel. The weight may now be allowed to fall, and before it reaches the floor it becomes detached from the wheel, if the cord be suitable in length.

It is necessary to estimate the energy yielded by the action of the earth on the hanging weight, and the energy gained by the flywheel, and stored up in it while it is rotating. The main fact of the transfer is sufficiently obvious. Under ordinary circumstances a heavy body would fall with great rapidity to the earth. When put in connection with the massive wheel, it descends quite slowly and the wheel rotates. When it is disconnected towards the end of its fall, it is moving with far less than the normal speed; it has lost potential energy without gaining the due amount of kinetic energy. But, meanwhile, the flywheel is rotating rapidly, and were it not for the friction of its bearings, it would continue to rotate indefinitely, unless stopped by some external constraint. Energy has left the suspended weight, and it now resides in the flywheel.

MEASUREMENT OF KINETIC ENERGY.

Kinetic energy, or the energy which a body possesses in virtue of its motion, is known to be proportional to the product of its momentum and speed. The numerical value of kinetic energy is equal to one-half the product of the numerical values of its mass and its speed squared. Or,

$$\text{Kinetic energy} = \frac{1}{2}MV^2.$$

The following considerations lead us to state, that $\frac{1}{2}MV^2$ always represents kinetic energy, or, in other words, that the numerical value of the kinetic energy, possessed by a body at any moment, is obtained from half the product of the numerical value of the mass into that of the velocity squared. It is quite true to state, that kinetic energy is proportional to the mass and the square of the velocity jointly, but it is a convenience to regard it as $\frac{1}{2}MV^2$ rather than MV^2 . By doing so, the numerical relation of force and energy, and of force and work, is more easily grasped.

Let F, M, S, T, V, stand for force, mass, length, time, and speed respectively.

Then a constant force, acting for the time T , causes an increase of momentum, which may be represented as $FT = M(V' - V)$.

In such a case, the mean speed is $\frac{1}{2}(V' + V)$, that is, the mean of the original and final speeds.

But $\frac{1}{2}(V' + V)$ also equals $\frac{S}{T}$, since the number of units of length, divided by the number of units of time taken, gives the average speed.

By multiplying FT by $\frac{S}{T}$ and $M(V' - V)$ by the equivalent of $\frac{S}{T}$, namely $\frac{1}{2}(V' + V)$, the accuracy of the equation is not altered, and we obtain the result—

$$FS = \frac{1}{2}MV'^2 - \frac{1}{2}MV^2.$$

Now FS is the expression for a force acting through a certain distance, and this is the performance of work. The quantity of work performed is measured by the difference in the value $\frac{1}{2}MV^2$ at the beginning and the end of the action of the force. This is shown in the expression $\frac{1}{2}MV'^2 - \frac{1}{2}MV^2$.

The performance of work is a transfer or transformation of energy. The accession of energy is seen in the changed value of the term $\frac{1}{2}MV^2$, and this is the term which we use to express kinetic energy in preference to MV^2 . Or we may put it in the following way, that starting with recognised definitions of force and work, the expression $\frac{1}{2}MV^2$ may be called kinetic energy.

USE OF A FLYWHEEL IN MACHINERY.

In ordinary steam or gas engines, the to-and-fro motion of the piston is converted into a circular motion by a *connecting-rod* and *crank*. The outer extremity of the crank moves in a circle, and one extremity of the connecting-rod moves with it, while the other end is constrained by guides to move rectilinearly. But it will be clear on inspecting an engine, or a model of one, that the turning of the crank will be irregular. The arrangement of the component parts of the link-work

necessitates this irregularity. It will be seen that there are two dead-points, points in a line with the guide-blocks of the connecting-rod, at which there is no turning power at all, and if it were not for the *stored energy of rotation* which carries them over these points, continuous rotation would be impossible. In addition to this feature in the link-work, by which rectilinear motion is converted into circular, there is a great variation due to the changing pressure of the gas or steam used in the cylinder. The working of the engine would be irregular and jerky but for the provision on the shaft of a large and massive **flywheel**, which stores up the energy derived from the more rapid parts of the stroke of the piston and equalises the whole movement. Hence it is, that the flywheel is a prominent feature in every engine, and the larger it is, the more steady is the engine. There is less jarring and vibration, and a more constant speed is maintained by the employment of a flywheel. Accessions of energy, which are more or less intermittent, are distributed evenly over the whole wheel, and are evenly handed on, by the belting and shafting, to the positions where they are needed. In the case of a locomotive, the flywheel is the large driving wheel.

WORK ESTIMATED AS PRESSURE EXERTED THROUGH A DISTANCE.

Fortunately for our comprehension of work, it is possible to approach it from several sides. So far we have looked on it as a change in the form of energy, or a change in the residence of energy. When kinetic energy changes to heat (*friction*), when thermal energy changes to kinetic energy (*engine*), when chemical potential energy changes to heat (*combustion*), when thermal energy changes to chemical potential energy (*reduction of ores*), when chemical potential energy changes to electric energy (*cell*), when electric energy changes to kinetic energy (*motor*), when kinetic energy changes to electric energy (*dynamo*), on all these occasions work is performed. At the same time we observe that the location of the energy alters. It passes from one body to another, while it changes its form.

But we may now regard the performance of work in another light. In some of its instances, and these the most familiar, we may perceive that a certain *pressure* is being exerted over a given distance. When a body is raised from the surface of the earth, a pressure, gravitation, is overcome. The greater the distance through which it is raised, the greater is the amount of work. The larger the quantity of matter which is raised, the greater is the quantity of work performed, and the quantity of matter in this case is a measure of the quantity of pressure. Matter is attracted to the earth in proportion to its quantity. Here we see clearly, that the product of the numerical value of the pressure and the number of units of distance gives us the numerical value of the work. Or, $W = FS$.

The total value of the pressure of steam on the piston of an engine, and the distance through which the piston is thrust, together measure the work done at each displacement of the piston. In a sense very similar to that in which we regard the pressure of a hot gas, as steam, we may look upon the **electromotive force**, or voltage, of a current as an electric pressure, and the product of this value into the quantity of current informs us of the rate at which work may be performed.

From these and other observations it is apparent, that the extent of work done varies with the value of a pressure, or something corresponding with a pressure, combined with the distance through which that pressure or its equivalent is exerted. And this conception of the performance of work is quite consistent with that which we obtain by regarding it as a process of transferring energy. It is, indeed, the same fact expressed in different words.

POWER.

A matter of very great practical importance now comes under discussion. The quantity of work performed on a given occasion may be important enough in itself, but the rate at which it is performed may be a question of still higher moment. It is not only necessary to know how much work is done, we may require to know how quickly it is done. *The rate of doing work is called*

power, and we may take it to be a *time-rate*. The quantity of work per unit of time defines the power. The quantity of energy transferred, or changed in form, in a unit of time gives the power or rate.

A slight change in our attitude towards the event will enable us to see, that the *space-rate* in the transfer of energy yields us the *intensity of the effort*. If a given amount of work is performed within a short distance, then the pressure must be correspondingly large. The smaller the distance worked through, the greater must be the pressure to perform a given quantity of work. From considerations of this kind we gain our conception of force. When work is performed in a *short space*, we speak of a *large force* existing. The greater the work done in a given distance, the greater is the force which does it. And this term **force** is useful and convenient in description, though it must not be forgotten, that what we are really dealing with is energy, its transferences and modifications.

It is interesting to note in connection with this branch of our subject, that the transfer of energy from one body to another in the form of heat is strictly parallel with the event which occurs, when a change of momentum takes place under the action of an impulse. The quantity known as heat is made up of mass and change of temperature, or $H = m(T - t)$, if we do not take into account the factor introduced by a difference in the kind of matter. In other words, a quantity of a certain kind of matter becomes changed in its thermal condition. So, too, does the action of a force (*i.e.* a transfer of energy) manifest itself as a change of state in a certain quantity of matter. The sole difference lies in the fact that the change takes place in the kinetic state of the body. $Ft = m(V - v)$. The action is jointly proportional to the change in velocity and the quantity of matter in which it occurs.

CHAPTER XI

DISTURBANCE OR DISPLACEMENT OF MATTER IS EVERYWHERE RESTRAINED

It becomes evident, when we reflect a little, that change is rarely *spontaneous*, and in the normal course of nature things remain as they are. The agency of **life** itself is the chief exception to this statement. If we except the events which are connected with life, we may safely say that no change originates itself. What is noteworthy in the first broad outlook on nature is the inertia of inanimate things, and what next claims notice is the frequent disturbance of equilibrium due to living things.

It remains for us to investigate the conditions which must be observed, whenever an attempt is made to disturb the existing state of affairs. It will be readily granted, that the displacement of every body is restrained and opposed, in a degree which varies according to circumstances. The terms, *restraint*, *inertia*, *resistance*, *effort*, and others, express an experience which is universal. The world, in most of its appearances and its characters, persists unchanged. Whenever we proceed to bring about any kind of change in things as we find them, we meet uniformly with difficulty. We experience a feeling of *resistance*, and a sense of *effort* to be expended. And this is what is meant by **work**—the effort necessary to bring about any artificial rearrangement of material, or to oppose a rearrangement which is taking place naturally.

If the description which is now given appears in any way to contradict that which was given in the last chapter, it will be due to the fact that we are now regarding work in a more special and more restricted light. The discrepancy will disappear, when we consider that work may be looked upon, either as *an operation of*

nature at large, or as an event which mainly concerns *living things*. The former view is the more comprehensive, but for the moment it is convenient to deal with the latter, as affording a suitable introduction to many important facts. And not least among them are the various means employed in counteracting some of the operations of nature.

There may not appear to be a sufficient reason for dealing with the properties of matter at this stage, but the reason may show itself in the scheme of statement which follows. On all sides we are surrounded by matter, continuous or discontinuous. The atmosphere, which continuously envelopes us, produces its own characteristic effects when experiments are made with it; water, too, exhibits special properties, and the solid matter on which we stand varies in its nature and yields to investigation a variety of results. And it is from the solid earth that most of the facts constituting Chemistry and Physics are derived. It exhibits to the chemist diverse properties and great variation in physical behaviour, while the Science of Mechanics is occupied in dealing with the behaviour of fragments of matter, which have been raised from the earth's surface and rearranged in space. By no contrivance can we escape from the effects of these surroundings. Nowhere do we find ourselves free from their influence. The properties which distinguish solids, liquids and gases, the modes in which their effects can be utilised or avoided, enter largely into the practice of life and the business of mankind.

COHESION.

The parts of every solid stick together in such a way that it is difficult to separate them. To effect a separation of parts in a solid, it is necessary to perform a comparatively large amount of work. In the case of liquids, the work needed to separate one portion from another is much less. Gases do not exhibit any appreciable cohesion.

The cohesion of the parts of a solid, though an obstruction in the way of an attempt to redistribute the matter composing them, is an important aid in overcoming other events. If it be needed

to remove any portion of matter from the earth's surface and maintain it in its position, we have recourse to this property of solids. **Structures** afford illustration of the way in which natural changes may be *restrained*, and, in addition, natural changes may be *utilised* by structural contrivances.

The existence of the minimum of cohesion in gases accounts for the freedom of our own movement, and that of other bodies, through the atmosphere of gas by which the surface of the earth is enclosed. The maximum of cohesion, shown by solids as a class, explains the conditions which regulate their displacement and, likewise, their effects upon one another. While a solid is acted on as a whole, and displaced as a whole, liquids and gases permit only of partial or local disturbances under the influence of the same agents. A solid preserves its shape when acted on by the earth, while liquids and gases do not exhibit as a rule either constancy of form or identity of shape.

FORCE AS A TERM WHICH SIMPLIFIES DESCRIPTION.

With a view to brevity, and, at the same time, to greater definiteness in the descriptions of matter under its various changes, a fictitious agent of change called **force** has been brought into use. But it must not be forgotten, that the term is merely an aid to description, and does not imply the existence of any new fact in nature. When this economical term has been accepted, we can describe with greater conciseness the manner in which the properties of solids are utilised in counteracting natural occurrences, as seen in roofs, bridges, etc., and the manner in which the movements of masses are controlled and modified, as illustrated in mechanical contrivances.

There is no better way of beginning the study of what is implied by the word *force*, than to attempt to realise how absolutely true is the statement, that things remain as they are, that they persist in their state whatever that state may be. Now this is but part of the general impression made upon us by what is outside ourselves. It is another description of the **constancy of nature**.

To use more technical terms, we should say that every object possesses *inertia*. If moving, it remains moving, or calls for some effort to alter its motion. If at rest, effort is needed to alter its state of rest. And what is meant by the inertia of matter is its inability to change. *The property of change must be transferred to it from elsewhere.* That which has been called effort, and is needed to alter a state of rest or motion, is another change *simultaneous with itself*. Or we may say, no change of state takes place by itself. It is brought about or *caused* by another.

This two-sided occurrence we have already learnt to look upon as a *transfer of energy* from one body to another. We have seen, too, that *force is an expression for the space-rate at which energy can be transferred.* All the varied changes which take place in nature are instances of energy being transferred from one body to another, and except for these exchanges, which arise mostly from disturbances due to living things, there would be little variation in the world. If the changes of temperature, and all the secondary effects produced by them, resulting from the alternate exposure of different portions of the earth's surface to the sun, were also absent, it is safe to say that *no changes would occur.* The various classes of change bring into existence a variety of names for so-called different forces. We allude, for example, to chemical, electric, magnetic, and other forces, although it is very probable that **all force is one**, however much its manifestation may differ by reason of a difference in the matter or in the ether affected by it.

Whenever any break occurs in the existing order, it is natural to attribute it to something external, to an **agent**. It is usual, indeed, to refer any change to something resembling human agency, the most familiar cause of a disturbance of nature's course. And so it comes about, that a figment of the brain called force is assumed to be *the cause of change*. Provided that too much be not associated with that term, there is a great convenience in its use. For this reason, it is usual to define force as *that which changes or tends to change a body's state of rest or motion.*

TRIANGULAR ROOF TRUSS, EXHIBITING SIMPLE MODE OF SUPPORT.

It may be quite easy to overcome stress, and in our practical life that which we have always to consider is the earth-stress or gravitation, but it is not always easy to overcome it in a convenient manner. Economy of material has to be considered, not only for the purpose of diminishing **expense**, for in a populous country the raw material, wood and stone, at our disposal is expensive, but also with a view to diminish the **labour** involved in handling cumbrous structures.

Any ordinary roof-structure will afford an illustration of a

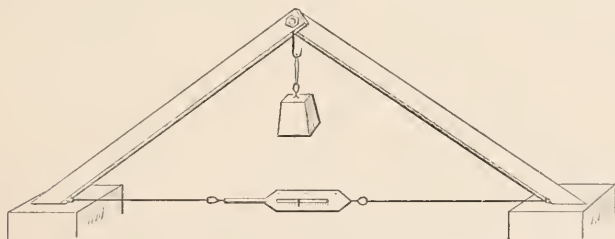


FIG. 28.—Model of a Triangular Roof Truss.

simple kind of framework, enabling pressure to be counteracted with economy as regards material.

Tiles or slates are needed to protect against rain, and the foundations upon which they are supported are a series of comparatively light wooden frameworks, arranged in the familiar triangular shape.

The model illustrated (Fig. 28) shows how the support is obtained, and how the different parts of the structure assist in the support. Two strips of wood, about 2' 6" long, are fastened at the top by a bolt and nut. At their feet they are tied by a cord in connection with a spring extension-measurer (to indicate the tension in the cord). The pitch of the model roof and the span covered may be varied by the length of the tie. The support, which this structure is intended to give, may be illustrated by hanging a heavy weight, 14 or 28 lb., from the top joint. Place the lower ends of this framework or *truss* upon supports.

Note the change in the reading of the spring, when the truss is loaded.

Vary the load. Note that the tie is extended, whereas the rafters themselves are compressed. Any structure which is extended in use is called a **tie**, and any structure receiving compression is called a **strut**.

Another simple form of triangular truss is shown in Fig. 29. Here we possess a very rigid framework, capable of withstanding a large amount of vertical pressure. The support, which the beam AB may give, is greatly increased in this example, and bending is prevented, by the tie-rod CD , the tie itself being suspended from C , and fixed to AB by a nut which permits an adjustment in length.

The beam AB may also be strengthened by an inverted strut at the centre. A weight placed on the beam is partially supported by the tie-rods CA , CB , for any bending in the beam would cause a lengthening of the ties.

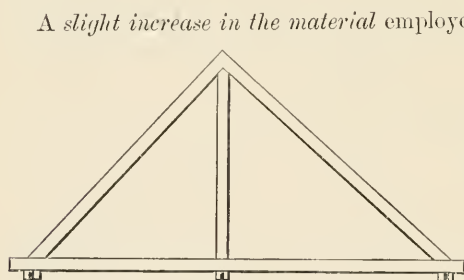


FIG. 29.—A Form of Roof Truss.

A slight increase in the material employed adds enormously to the strength of the structure in all these examples of framework. The plan of the framework, and the arrangement and dimensions of its parts, determine whether it is strong enough for its purpose, and whether that strength has been obtained in the best and most advantageous manner. Plenty of modifications of framework may be seen in roofs and bridges by an observant person.

THE DISTRIBUTION OF PRESSURE IN A SIMPLE CRANE.

An ordinary spring compression-measurer is placed at an angle on a base, as in Fig. 30, and the wooden jib of the model crane is attached to the spindle of the spring. At the upper end of the jib a small pulley is fixed, and over this a tie in the form of a cord or light chain passes. At one end of the cord the weight to be supported is fixed. Between the pulley and the firmly fixed upright is placed an extension-spring, and the tie is continued through one of the several rings which are placed in the upright, and finally fixed at the base. The angle of this tie can be altered by using different rings.

Use different weights and different angles for the tie. Note in each case the values for the *compression of the jib* and the *extension of the tie*.

BRIDGES.

Various modes of construction are adopted in bridge-making. In all cases a structure is required, which is secure against wind pressure, and is capable of carrying the required load with a large *margin of safety*. But these ends must be reached with as little material as possible, for the *dead weight of the structure itself* becomes a serious matter in a bridge of long span.

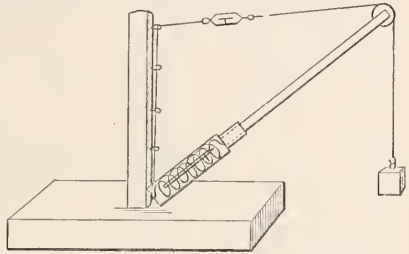


FIG. 30.—Apparatus to show distribution of pressure in a crane.

If a bar of indiarubber marked with vertical lines be supported at each end, and a body heavy enough to bend it be suspended from the middle, it will be noticed that the parallel lines converge to a point as shown in Fig. 31.



FIG. 31.—Indiarubber bar marked with parallel lines and bending under weight.

When a solid bends under a weight, it is clear that the upper parts of the solid are in a state of *compression*, while the lower parts are *extended*. In any framework, arranged to support a load, these facts must be taken into account. The parts under compression should be, as far as possible, *short* and *thick*, while all parts liable only to extension may be *thin* and *light*. When a pull is exerted, the **tie** which resists it may be a chain, rope, or rod, whereas a thrust must be met by a relatively thicker and more rigid bar, called a **strut**.

A common form of framework is shown in Fig. 32. Here the strength of the girder or beam is greatly increased by two struts and the ties *AC*, *CD*, *DB*.

In the **Suspension Bridge** shown in Fig. 33 it is clear that the various parts of the platform, forming the roadway of the

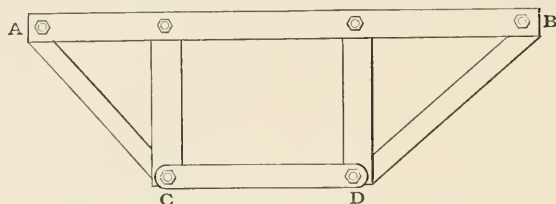


FIG. 32. - Diagram of supporting framework.

bridge, are supported by a series of vertical rods hanging from the chain. The main support of the bridge lies in the chain, and



FIG. 33.—The Suspension Bridge.

this is firmly attached at each end, outside the piers *A* and *B*. The space to be bridged over may be too great to be spanned by

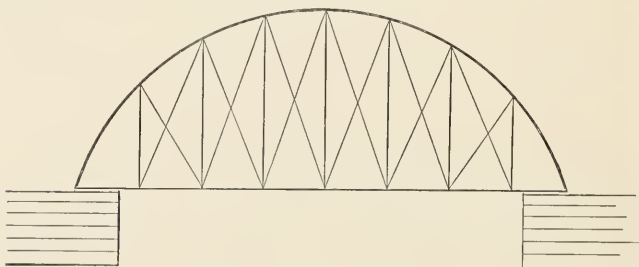


FIG. 34. - The Bowstring Girder.

a single continuous girder, though the parts may be riveted together, and some rigidity gained in that way.

In another form of framework-bridge, the roadway is suspended from an arch placed above it, as shown in Fig. 34. The platform carrying the roadway serves as a tie taking the strain of the arch, which tends to flatten with its load, in the fashion of a strung bow. For this reason it is called the **Bow-string Girder**.

The inverted form of the suspension bridge is seen in Fig. 35. Here we have the **Parabolic Arch**, the parabola being a curve which is also used in the suspension bridge. The load now presses upon the arch instead of hanging from it, and the vertical

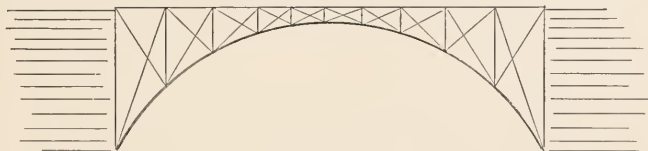


FIG. 35.—The Parabolic Arch.

rods are compressed, instead of being in tension, as occurs in the suspension bridge.

DESIGN AND MATERIAL OF STRUCTURES.

It is clear that the design and material, employed in structures, must be considered together. The *arrangement* of the material must be such as will agree with its *properties*. The use of *stone* and *brickwork* for support against the heaviest vertical compression is common, and its use for foundations is essential. *Hollow iron tubes* are frequently employed, as being capable of withstanding great compression. For bridging over spans, either for a roof or to carry a roadway, light frameworks of wood or iron are needed, and some of the frameworks which are employed have been described. In all of them, there are two properties of solid matter to be considered, its resistance to compression and extension. The *material* which offers the best resistance to these stresses is employed in its appropriate position, considerations of expense or labour not interfering. The *design* adopted will be, in the absence of limitations due to the requirements of

taste, that which permits the stresses, likely to occur, to be resisted most directly and most economically.

The behaviour of various solids to the different stresses can be readily ascertained by experiment. And the thought suggests itself very forcibly, in this connection, that the qualities which are most characteristic of the solid body are those which are the most useful. The resistance to stress, which results from the cohesion of the particles of a solid, *i.e.* the capacity to counteract a pressure, without undergoing an alteration of shape, marks the solid. And on every occasion when solids are employed in structure, cohesion comes into prominence, and the distinction between solids and liquids is made clear.

STRENGTH OF MATERIALS.

A few observations of the strength and stiffness shown by small rods of steel and wood will afford an insight into the behaviours of larger beams under loads, and will give an indication of the factors which have to be considered in the planning of structures.

The **strength** of material is an expression denoting the magnitude of the load it can support or carry. The **stiffness** of a body is a term denoting its resistance to bending or deflection. Both strength and stiffness are in reality ratios, and must be taken in connection with the dimensions of the bodies in question. The *stress per unit of area*, which a body is capable of bearing without breaking, stands for the strength, while the relative stiffness of two bodies will be estimated by the loads needed to produce the same *deflection* in each. These are the two most important properties of matter to be considered in erecting structures, but our observations are confined to the investigation of deflection alone, inasmuch as experiments on the breaking-stress are surrounded with disadvantages as well as difficulties.

THE RELATION OF DEFLECTION TO LOAD AND TO DIMENSIONS.

A rod of ordinary tool steel is supported on knife-edges. A load is suspended at its centre, and the deflection produced under an increasing

load is observed, by watching the movement of a pointer against a millimetre scale fixed vertically behind the rod. The pointer may be arranged by fixing a pin, with its point upwards, by means of wax, upon the upper face of the rod at its centre.

It will be found, that deflection is *directly proportional* to load, provided the load be not increased beyond a certain point. Similar observations may be made with *wooden laths*, and in their case, too, it will be found, as a rule, that the deflection increases with the load, though variations in texture may cause irregularities of behaviour.

Use rods of twice the **width**, or place two rods side by side, and notice that the deflections, which will again be proportional to the load, are, on each occasion, *one-half* what they were before. The deflection of a beam is *inversely proportional* to the breadth.

Use the same rods as before, but turn them on their side and ascertain the bending produced by various loads in this case. It will be found, that the deflection is proportional to the load, but it is much smaller in each case than it was before. An increase in **depth** adds to the stiffness of a beam *far more rapidly* than an increase in **width**.

Use two rods of the same width, but with depths in the ratio of 2 to 1. The deflection for each load will be one-eighth in the case of the deeper rod what it is in the thinner one. The bending is here *inversely proportional to the cube of the depth*.

It is evident, that the most effective position for a beam is that in which it presents its largest dimensions to the pressure it has to resist. A beam placed "*on edge*" is far more advantageously used than when it is placed flat.

Similar observations may be made, when the ends are *fixed* by clamps, instead of being merely supported. The deflections will be found to be considerably less, something like one-fourth what they were before.

Again, the *length of span* is a very important factor in these experiments. It will be found, that as the span is increased the bending becomes very marked. The results observed may not appear to follow any *definite law*, but the extent of bending will increase in some cases *approximately as the cube of the span*.

DIMENSIONS OF STRUTS AND TIES.

It will be obvious that the resistance of a rod to compression is very different from its resistance to extension. If we consider for one moment the behaviour of a *very thin rod*, or a wire, the distinction becomes clear. A wire may be able to resist a **tension** of many pounds' weight, while its capacity to resist **compression** is practically nil.

The *shorter* a body, the greater is its resistance to compression, and its resistance also increases very rapidly with its thickness. The loads required to crush short thick columns are too great to be observed experimentally. The slightest bending of any strut is a sign of danger and instability. The shape of struts, and the auxiliary supports needed to prevent bending, are matters of the greatest interest to engineers. The strength of a tie is a matter of simpler observation, for a direct pull does not present the same irregularities as a thrust.

CONDITIONS OF EQUILIBRIUM.

However force may be regarded, whether we look on it as existing independently of the changes by which it is recognised, there can be no doubt that any given body may, on account of its inertia, be unmoved under conditions, which would bring about the displacement of a smaller quantity of matter. It is incorrect to say that such a body is uninfluenced in this case. Influenced it must be, though the influence be not observable. It is only necessary to substitute a body more susceptible, to observe that a change may be produced. In all cases where any displacement of matter is possible, a body is either actually displaced or some strain produced in it. There are many instances in which this strain escapes detection, owing to the nature of the body. The solid, for example, may undergo a stress without visible effects being produced, whereas a liquid may be readily made to show the existence of a very slight stress. The susceptibility of a gas to change of temperature (which is indicated when it is enclosed in a vessel so as to freely admit of an extension of volume, an arrangement adopted in the *air-thermometer*) and also the ready movement of a liquid under change of pressure, as shown in a *barometer*, plainly illustrate this statement.

Attention has been directed in the last chapter to the existence of a universal resistance to change, and that, in order to overcome this resistance, effort is needed. Another aspect of the same state of affairs presents itself in the fact, that every body, every portion of matter, whatever may be its locality and circumstances, is in a

state of stress. Nowhere do we come across matter free from stress, and in most cases it is suffering a complication of stresses.

It is not difficult to imagine situations in which this statement would not hold, and it has become necessary, in the pursuit of science, to consider and reason about bodies, free from the influences under which we know them to exist. Yet important as this knowledge of the behaviour of bodies under ideal conditions may be, and greatly as it may increase our understanding of the actual world, it must not be forgotten, that all such *abstract science* is based upon observations of the world *as it is*, nor must we lose sight of the fact, that the world in which we practise is very different from the world of abstract mechanics.

The first law of motion,¹ as laid down by Newton, gives an excellent illustration of this principle. The conditions necessary for it are not possible on the earth. Nowhere does such an event as perpetual motion come before us, unless we include in our observations the movements of the earth as a whole, and of similar bodies in space. But not even in these bodies do we ever perceive perpetual motion in a straight line. Yet the statement made in that law fits in with all the rest of our knowledge about moving bodies, and we are convinced of its truth, *that every body persists in its state of rest or motion, except so far as it is restrained by force*. There is, in truth, no experience which is at variance with this statement, and the more closely its conditions are obeyed, the more closely do we approximate to the fact. Moreover, no fuller or wider statement than this, regarding the motion of bodies, has ever been suggested.

The universal existence of stress and the constancy of inertia are facts, which force upon us the necessity of investigation and inquiry. The conditions which conduce to equilibrium may be conveniently dealt with in the first place, and we mean by equilibrium a state of rest with regard to surrounding bodies, which persists in spite of any causes tending to produce change. It may appear inconsistent with what has been already laid down to speak of causes *tending* to produce change. It would seem that these causes are only too ready to produce their effects, and that

¹ P. 238.

a state of change is a normal one. But this is not true. The normal state of affairs is one of **equilibrium**. No change can take place unless that state of equilibrium is first of all disturbed, and it is not strictly necessary to assume that a tendency to change always exists independently of this disturbance. But without attempting to revise this hypothesis, we shall find that it furnishes us with a very convenient scheme of description, and permits many diverse facts to be explained in a manner which has, at least, the merit of being consistent.

SIMULTANEOUS DISPLACEMENT IN TWO DIRECTIONS.

Suppose a body to be acted on, in such a way that it is displaced along a path AC , in a given interval of time. Now at the

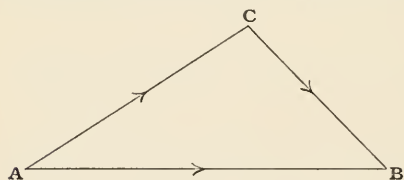


FIG. 36.—Diagram of Displacement.

termination of this occurrence, suppose a second cause, no matter what it may be, to operate so that it is displaced, in the same interval of time, along the path CB . It is clear, then, that the joint

effect of the two acts of displacement is the same as if the body had been displaced along the path AB . (The final effect, of course, is that the body has been moved from A to B . The path AB itself has not been taken, though that line represents the magnitude of the displacement on this or any other occasion when the body is moved from A and left at B .)

In the next place, suppose that the same two uniform causes act *simultaneously* upon the body. Then it can be proved, that, during the interval of time agreed upon, the body will necessarily have moved along the path AB , and no other. But the diagram here drawn (Fig. 36), may be put to still further use, and the statement already made introduces us to a further development.

Instead of limiting ourselves to the single instance, we may say, that any one side of a triangle may be taken to represent in magnitude and direction the displacement occurring, when a

given body is simultaneously acted on by two causes, able to produce, in the same interval of time, if each acted separately, displacements represented in magnitude and direction by the other two sides of the triangle.

Moreover, a similar statement may be made about any number of displacements, provided they can be separately and consecutively represented in magnitude and direction by the sides of any enclosed figure. Little consideration is needed to understand why it must be an enclosed figure. To represent faithfully a body under the simultaneous action of two agents, where one line ends, the other must begin, and we have to imagine each effect produced independently.

The body is supposed to travel, for example, along AC , and then along BC . As a matter of fact it travels along AB . But the chief value of this mode of representation will be found in the fact, that AC and CB represent the agents themselves quite as much as the effects they would separately produce. And AB stands for the **joint agency** as well as the **joint result**.

Each force creates its independent displacement, and the extent of the displacement, in the unit of time, serves as a measure of the force. There is nothing to be learnt about force, except its magnitude and line of action. The magnitude is ascertained from the displacement acquired during the unit of time, and forces may be compared by the displacements taking place in equal periods of time. For this reason, *lengths of line* afford a convenient mode of recording the *magnitudes of forces*, and it is clear that the *path* (direction and position) of a force can be readily indicated by a *line*.

Moreover, since the lines are drawn to represent the displacements which would take place in the same interval of time, we may likewise consider them to represent **velocities**. We then have a diagram of velocities, instead of a diagram of displacements. We may now say, that when two forces (for it may be admitted that throughout this exposition the word *agent* or *cause* has been used instead of the more customary term *force*) act upon a body at the same time, the **resultant force** may be calculated, in direction and magnitude, by the same mode of reasoning as we have just given.

Now when it is realised, that the joint effect of two or more agents or forces is readily to be ascertained, we may go a step farther, and perceive, that an agent or force, which in its effect is equal and opposite to their resultant, is capable of counteracting them, and it becomes the *necessary condition of equilibrium*.

In order to maintain a body in equilibrium, when it is under the influence of known forces, their resultant must be found and counteracted.

The magnitude of this required force is *equal* to that of the resultant; its direction is *directly opposed* to that of the resultant.

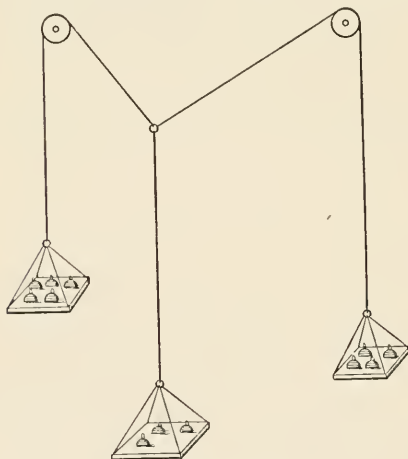


FIG. 37.—Apparatus for observations on three forces in equilibrium.

In the arrangement of the parts of a structure, or a machine, the principles which govern the relations of component forces and their resultants are bound to be considered. That construction is the best, in which the pressures are received by material, so placed that they are counteracted in the most efficient way. The parts must be placed in a position to

meet the pressures along their line of *greatest strength*. In the case of structures, the equilibrium will then be the most *stable*, and in the case of machinery, the motions will be the most *rigidly constrained*.

OBSERVATIONS OF THREE FORCES IN EQUILIBRIUM.

By means of cords passing over pulleys (as shown in Fig. 37), with different weights attached to their free ends, the conditions under which two forces balance a third may be ascertained. A suitable weight is attached to a third cord for the purpose of balance. The conditions ascertained will be

simply a question of the direction in which the forces act, and this is shown by the shifting position taken up by the cords as the weights are varied. A small ring serves as the meeting-point of the three tensions.

The true value of the tensions may be disguised by friction in the cords or pulleys, but this may be overcome, by slightly displacing the cords and allowing them to run back freely.

A board, with paper pinned on it, is placed at the back of the cords, and this permits the position of the cords to be traced on it.

Remove the paper, and mark off, along the lines representing the direction of the forces, distances which represent the magnitude of the forces engaged. For every unit of force, say the weight of one ounce, allow a unit of length, say one inch.

Vary the weights and take a number of observations, keeping the papers separate, and marking the magnitude of the forces.

At the end of your observations show on each diagram, that the vertical line, if produced upwards to a distance representing the magnitude of the force engaged, will form the diagonal of a *parallelogram*, of which the two other lines represent adjacent sides.

Or, if two forces, acting at a point, be represented in magnitude and direction by the adjacent sides of a parallelogram which meet at the point, then their resultant is represented in magnitude and direction by the diagonal of the parallelogram passing through that point.

Again, a little consideration of the lines will show, that in all cases, when three forces are in equilibrium, they may be represented in magnitude and direction by three sides of a triangle taken consecutively.

This important condition for equilibrium between three forces may be further illustrated, and it is imperative that it should be thoroughly understood, because of its frequent application in practical affairs. It may be pointed out at this stage, that we have spoken of one of the forces as the resultant of the other two, but it is clear that *any one* of the forces may be looked on as the resultant of the *other two*. It is a matter of indifference which one we select. There is equilibrium between all three, and any one may be regarded as the cause of equilibrium when combined with the others.

Tension in Cords.—A slight modification of the apparatus employed in the last experiment will lead to interesting results. Fix two spring

extension-measurers by cords to hooks (Fig. 38), and attach the other ends of the springs by short lengths of cord to a ring, and also hang a weight to the ring. It will be found not only that the extension of the springs varies with the weight, but that it varies with the angle made by the cords carrying the springs. This angle may be varied by adjusting the length of the cords, and also by shifting the point of attachment of one of the springs.

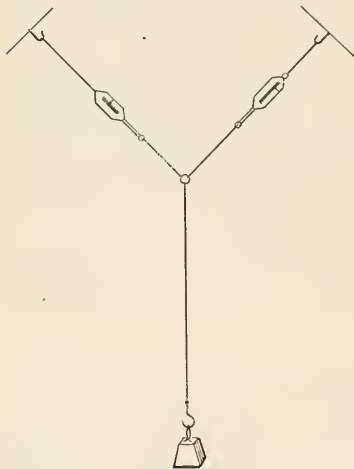


FIG. 38.—Apparatus for showing tension in cords.

Paper, pinned to a board at the back of the cords, permits the direction of the forces to be drawn upon it, and their magnitude may be represented *graphically* as before.

The principle already described will be found to hold good on all occasions, if the tensions are made to vary. The condition again holds true, that all three forces shall be capable of representation, as regards magnitude and direction, by the

sides of a triangle taken in order.

If a cord carrying two springs, with a ring at its centre, is now tightly stretched in a horizontal position, so as to cause a considerable extension of the springs, it will be found, that a very slight weight, attached to the ring at the centre, is capable of deflecting the cord from the straight line, and capable of extending the springs very considerably. When the triangle, representing the forces, assumes the shape of

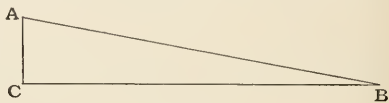


FIG. 39.

Fig. 39, a *very small force* is found to balance two *very considerable forces*.

A practical illustration of this occurs, when a very tightly strung chain is broken, as it may easily be, by a thin cord, fastened at its centre and pulled at right angles to it. Or, again, when a piece of cotton is passed through the ring of a two-pound weight, which it is easily capable of raising when the two ends are kept together, the tension required to balance the weight becomes so great, when the ends are separated, that the cotton

breaks. *The larger the angle made by the two parts of the cotton, the greater the tension becomes, until the snapping-point is reached.*

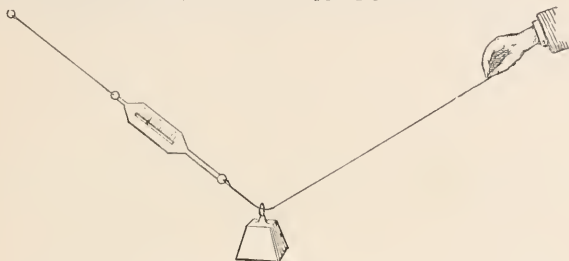


FIG. 40.—Apparatus to show variation of tension due to position in a string.

A cord, fastened at one end and free at the other, will show the same result, if a spring be inserted in the cord. A weight hangs from the cord as shown (Fig. 40). It may be assumed that the tension of the cord is the same throughout. When the angle made by the two parts of the cord is made larger, the tension increases. When the cord is stretched as near as possible to a straight line, its tension is at the maximum.

Note, that if any weight is capable of bending the cord at all, *no force, however great, can stretch the cord again to a perfectly straight line.* Did this occur, we should have an instance of one force held in equilibrium by others acting at right angles to it.

CONDITION FOR THE EQUILIBRIUM OF MORE THAN THREE FORCES.

An extension of the results, embodied in the proposition known as the parallelogram of forces, may be obtained by arranging for *more than three forces* to meet at a point. This may be carried out on the same plan as before, using four pulleys, instead of two (Fig. 41).

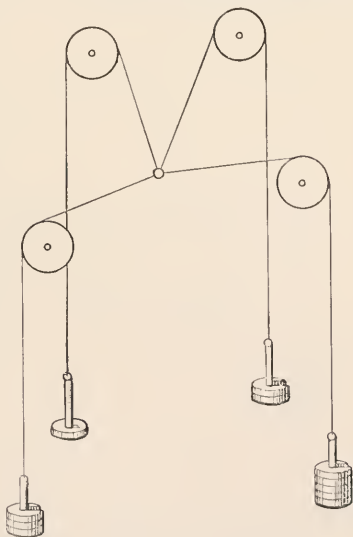


FIG. 41.—Apparatus for illustrating conditions for equilibrium of four forces.

If the forces here exerted are again represented, in direction and magnitude, by lines *drawn in succession* on paper, every fresh line starting where the last one ended, it will be found that a closed figure is obtained.

Several observations should be made, varying the forces by using different weights on each occasion, and the following proposition will be found to be true, if we make allowance for slight inaccuracies, due to friction at the pulleys or to stiffness in the cords.

If any number of forces, acting at a point, be in equilibrium, then lines drawn from end to end, to represent the forces in magnitude, direction, and order, will form a closed polygon. This is known as the proposition of the **Polygon of Forces**.

EXAMPLES OF SOLID CONSTRAINTS AFFECTING THE CONDITIONS OF EQUILIBRIUM.

The Inclined Plane.—A body, supported on a smooth

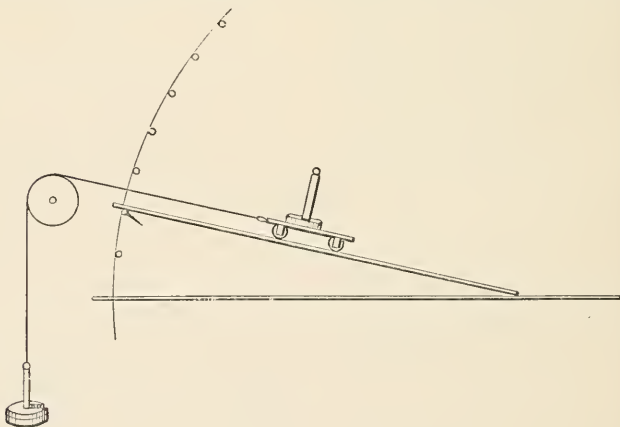


FIG. 42.—The Inclined Plane.

inclined plane, is maintained at rest, by a force considerably smaller than that due to its own weight.

A smooth board, hinged at its base, so as to admit of the angle which it forms with the horizontal being varied, is required. A pulley, capable of being raised or lowered vertically, is fixed near the top. Over this a cord passes, and maintains the object at rest upon the plane. In order to avoid,

as far as possible, the effects of friction, this object runs on wheels. A ledge fixed on it permits additional weight to be given to it. The force needed to maintain this body at rest is estimated by the weights placed in the pan at the end of the cord. Fig. 42 illustrates a suitable form of apparatus. Various observations may be made :

First, an independent experiment to show that a rough body, a block of wood, for example, may be supported on a rough board by *friction alone*, even when the board is inclined at a considerable angle—

Second, the forces needed to balance varying forces acting down the plane, that is, the forces due to various weights on the plane—

Third, the varying force needed to maintain equilibrium, as the angle of the plane is increased. As the angle increases this force increases.

In these experiments we may observe a series of states of equilibrium, in all of which the principle of the *triangle of forces* comes into view. Three forces are engaged, *the weight of the body, the resistance of the plane, and, lastly, the tension of the cord*, which may be regarded as counteracting the other two, that is, balancing the resultant of the other two forces.

The weight acts vertically. The resistance of the solid plane

is at right angles to its surface, and the support given by the tension of the cord is along the plane. Fig. 43 illustrates the direction in which the several forces act. It only remains to consider their relative magnitudes.

The magnitude of two of the forces is already known, namely, the weight and the support. Draw lines to represent these two forces in magnitude and direction, then the line joining their extremities represents in direction and magnitude the resistance of

the plane. The ratio of the weight to the support (or $\frac{W}{S}$) measures the **mechanical advantage** of the plane. A little reflection will make this clear.

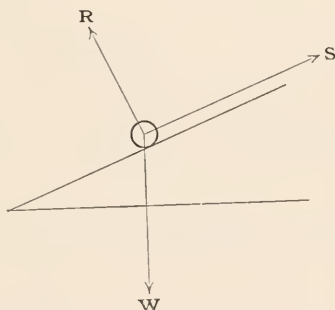
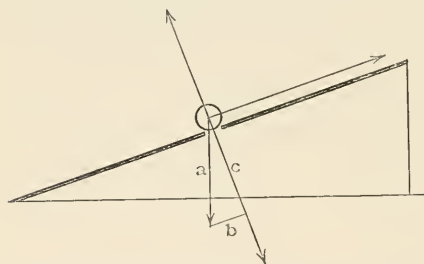


FIG. 43.—Diagram of direction of forces on an inclined plane.

W = Weight. S = Support.
R = Resistance of Plane.

The diagram shown in Fig. 44 expresses the conditions necessary for the equilibrium of a body resting on a plane. It is evident, that the triangle representing the forces is similar to the right-angled triangle containing the angle of the plane itself, and, consequently, the relation of the forces in action will vary with the angle of the plane. The *base* of the plane corresponds with the line in the triangle of forces which represents the *reaction of the plane*. The *length* of the plane corresponds with the *weight*

of the object. And the *height* of the plane corresponds with the *force along the plane*.



CONSTRAINT DUE TO A RIGID BAR. THE LEVER.

FIG. 44.—Diagram expressing conditions necessary for the equilibrium of a body resting on a plane.

The mutual changes occurring through the medium of a lever have already been described.

It has been shown, that the situation with regard to the principle of work is easy to understand. The effort expended is equal, and exactly equal, no more, no less, to the work done. But we have not yet considered the manner in which the lever serves as a means of gaining **mechanical advantage**.

There is no antagonism, in the use of the lever, to the great principle, *that the effort expended is equal to the work done*, or, to express the same fact in different words, that the quantity of work done at each end of the lever is the same. There is no contradiction here, indeed, to the statement, *that energy can never be increased or destroyed*. In the lever and in other machines, all that we can do is to *transform* energy or *change its situation*, in a manner convenient to ourselves. And we are enabled to do this, through the constraint exercised by a solid body, just as we were able to utilise the constraint of an inclined plane for the partial support of a weight.

Apparatus.—A rigid bar is supported at a given point called the *fulcrum*. To permit freedom of movement, the fulcrum should be a knife-edge. The bar may be of thin iron, placed on its narrower face, in which position it is less liable to bend. (For the same reason, beams and rafters are always placed so as to submit the larger dimensions to the greater stress.) It is marked by vertical lines at equal intervals, say inches or half-inches. Weights may be attached by means of S-hooks of wire.

In investigating the action of a lever, we must not lose sight of the fact, that the material, of which the lever itself is made, is under the *action of gravity*. If the total quantity of matter of

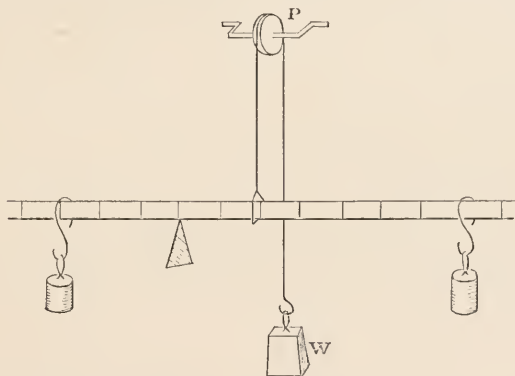


FIG. 45.—Apparatus arranged for experiments on the lever.
The weight of the lever is balanced by the weight (*W*) attached to the cord passing over the pulley (*P*).

each side of a blunt fulcrum is exactly the same, it may be possible with great care to balance the lever at this point. If the material be homogeneous, this point would be at its geometrical centre. In this case, the length of lever on each side of the fulcrum would be the same. In other words, the **arms** of the lever would be equal.

But it is useful to be able to vary the length of the arms at which our forces operate, and we need, for our observations to be correct, to overcome the weight of the lever itself. This may be readily done by supporting the lever from its centre, by the aid of a cord passing over a pulley and carrying a weight, as shown in Fig. 45. The weight may easily be adjusted to balance the lever, so that its own weight need not be taken into account, and we may make use of its *rigidity alone*. The length of the arms may

now be varied at will, and the weights which are utilised as forces may be placed at any position, without it being at all necessary to take into consideration the forces due to the weight of the arms themselves.

Prove with this apparatus, by varying the weights and their distances from the fulcrum, *that the product of the force multiplied by its distance from the fulcrum is the same for both arms*, and that the greater the distance away from the fulcrum at which a force is applied, the greater is the force on the other side of the fulcrum which it can balance.

The product of a force into the perpendicular distance of its line of action, from the point on which the body turns, is called the **moment of the force** about the point. The moments on each side of a lever at rest must be *equal*. For a given force, the moment (or *torque*) is greater, the farther the application of the force is away from the point or axis on which the body turns.

In the case of the lever here illustrated, the two moments tend to turn the body in *opposite directions*, but, since they are equal, no turning occurs. But it must not be forgotten, that these two opposed moments can only balance one another by means of the properties of the solid upon which they act. There must be a *state of constraint in the lever itself*, which forms another and an important item in the balance. *Two equal moments and a strain* bring about the equilibrium.

And a similar statement may be made about the inclined plane. Two forces, the weight of the body at rest on the plane, and the tension of the cord along the plane, balance one another *by means of the resistance of the plane to compression*. The smaller the tension of the cord for a given weight, the greater the pressure upon, and consequent reaction of, the inclined plane itself.

A bell-crank lever turning on an iron pin and having a spring-measurer attached to its shorter arm, as shown in illustration (Fig. 46), permits of various observations being taken. The moment of turning, shown by the extension of the spring, will be found proportional to the product of the weight employed on the longer arm and its distance from the fulcrum.

THE RESTRAINTS NEEDED IN CONVERSION OF RECTILINEAR INTO CIRCULAR MOTION.

In the action of the piston of a steam-engine, with its connecting-rod and crank, we have a familiar example of **con-**

version of motion. On inspecting the same, it will be seen, that the necessary constraint is obtained from very solidly bedded *guides*, and very firm and true *pinning* at two positions. In all kinds of machinery we find illustrations of these two main methods of constraining motion and rendering it determinate,

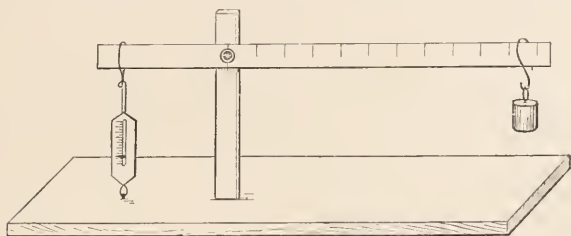


FIG. 46.—The Bell-crank Lever.

namely, (1) *the groove or slot to allow sliding alone*, and (2) *the pin and eye to allow only turning*. The effect obtained is that of a very true **reciprocating** (to-and-fro) **motion** giving rise to a circular motion, and the component movements engaged in this process are the oscillation of the connecting-rod upon its pin, and

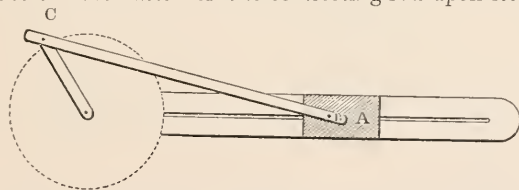


FIG. 47.—Apparatus for converting rectilinear into circular motion.

the complete turn of the crank upon the pin which connects it with the rod.

The link-work employed both for this purpose and also, in the opposite direction, for the purpose of obtaining reciprocating motion in the *slide-valve* from the circular motion of the shaft, is best understood by cutting out pieces of cardboard, or, still better, preparing wooden models. In Fig. 47 the block *A* stands for the cross-head of the piston. It reciprocates between the wooden guide-bars, and the connecting-rod turns on the pin *B* fixed in the block. The other end of the rod, being constrained by the pin *C*, makes a complete circle. Note that there is a *dead-point* in one of the conversions.

The model shown in Fig. 48 demonstrates, that circular motion may be obtained by two linear constraints, placed at right angles to one another. The reciprocating motion of the bar *A* between its guides causes the block *B* to describe a circle when constrained by the crank *C* and the slot in the cross-piece.

Friction.—Wherever constraint is exercised, and wherever one surface moves in contact with another, there rubbing or *friction* must occur, and loss of energy must take place. Wherever motion is constrained, and constraint is the essential function of mechanism, the object is to lessen the loss as far as possible. Wherever one surface turns or slides upon another,

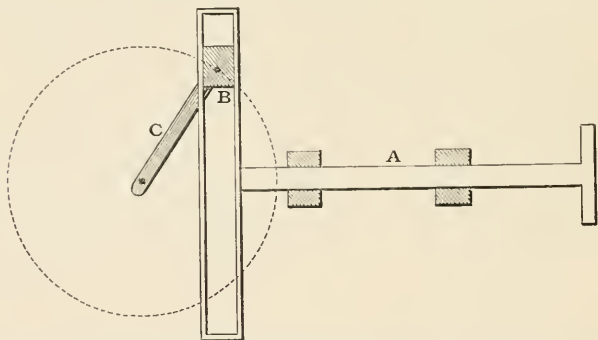


FIG. 48.—Model for demonstrating how circular motion may be obtained by two linear constraints placed at right angles to one another.

material which resists wearing and grinding must be employed, and it must be smooth and well lubricated. The existence and magnitude of friction may be readily demonstrated by a few experiments.

Place a heavy body, a 7 lb. weight, for example, upon a straight board, and note that the board may be turned through a considerable angle before the weight begins to slide.

From our observation of the conditions of equilibrium for a body resting on an inclined plane, we know that the body is prevented from sliding by something which is *equivalent to a force acting up the plane*. Motion down the plane is restrained

in this case by that which is equivalent to a force in the opposite direction. *And this is friction.*

Friction opposes the relative motion of bodies in contact, because motion under these circumstances implies a certain amount of *work* being done in the wearing away of the surface in contact. And as this work is not part of the scheme of mechanism, and would be avoided if possible, wherever friction occurs, energy, as a rule, ceases to be available.

It sometimes occurs that friction is utilised. For example, the friction between belting and pulleys serves to *hand on energy* from one shaft to another, and the friction between the rails and the wheels of a locomotive causes the locomotion. But it is most commonly a cause of a serious loss of efficiency in mechanism, in other words, *the energy leaving the mechanism is not equal to that which enters it.*

OBSERVATIONS OF FRICTION—SLIDING SURFACES.

A flat square board is provided with a small hook, to which a cord may

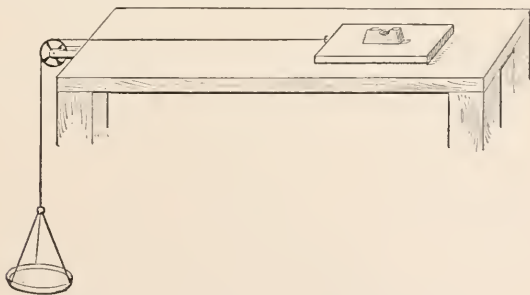


FIG. 49.—Apparatus for observations on friction.

be attached, at the centre of one end face. The surface of the board is planed, and it is placed so as to be able to slide upon the surface of a longer planed board, on the end of which a pulley is fixed as shown in Fig. 49. The pulley is fixed so that a cord passing over it may exert a straight pull upon the sliding board. Different sliders may be used, varying the nature of the wood and the direction of the grain, and different weights may be placed upon the slider, in order to judge the effect of varying pressures upon the surfaces in contact.

The force needed to overcome friction is estimated by the weights which have to be added to the pan at the end of the cord. But it is important, if correct values are to be obtained, that the surfaces should be plane, and the board be quite horizontal. This may be tested by a spirit-level.

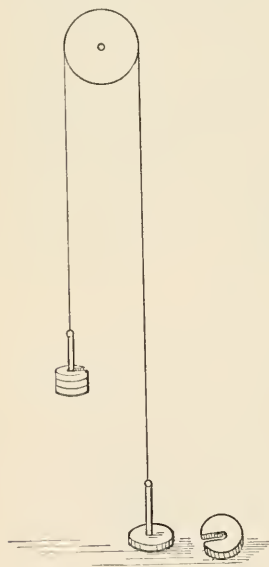


FIG. 50.—Arrangement of pulley and weights for investigating friction in a pulley.

It will be found, that the force needed to start motion is not the same as that which maintains it when once started. The *friction of rest* is greater than the *friction of motion*. The weights which need to be put in the pan, in order to *start* steady motion of the slider, are larger than those which are required to *keep up* a steady motion, when the slider has been started by hand. A little practice will enable you to hit off this point accurately. If too much weight be added, an *accelerated* motion will be produced. This must be avoided in either case.

The results must be recorded in a tabular form, varying pressures between the surfaces of contact being used, and different material and different areas being employed for the sliding surfaces.

Friction in a Pulley.—The friction occurring in the turning of various kinds of pulleys should be investigated, and the change made in the value of the friction, by varying the loads carried by the pulleys, should be ascertained. A cord passing over the pulley has attached to it, at each end, either pans, or, what are more convenient, supports which admit of successive weights being affixed in the manner illustrated (Fig. 50). Equal weights are attached to the ends of the thin flexible cord, made of silk by preference, and the small additional weight required to produce a slow movement is observed. The observations should be recorded in a table representing both the loads and the friction for each load.

CHAPTER XII

PHENOMENA DUE TO VIBRATIONS

MATTER in some form or other is necessary for the propagation of sound. Sound is usually conveyed to our ears by the medium of air, but it may be carried by any elastic material. The scratching of a pin on an iron pipe may be heard at some distance away by placing the ear against the pipe, but non-elastic material, bricks and mortar, for example, will not carry sound. Matter is said to be **elastic**, when a large stress is needed to produce a strain or alteration of shape. And the more elastic a body is, the more rapidly does it resume its original shape, and the distortion disappear, when the stress is removed. Glass and steel are very elastic bodies, whereas indiarubber is very *extensible*, but *not elastic*. Liquids are elastic, and so are gases, though in a less degree. The elasticity of air is what enables it to convey sound.

But the envelope of air which surrounds the earth is known to be limited in extent. It diminishes in density rapidly as the distance from the earth increases, and it cannot be regarded as extending very far. Some other medium of communication is needed for the transfer of radiant energy from the sun and other stars. The atmosphere may convey the disturbances which originate sound, but it cannot connect us with events taking place outside its limits. The existence of a medium, whereby energy from the sun, in the form of light and heat, reaches us, is placed beyond doubt, and it is called the **ether**. The certainty with which we are able to infer the existence of this ether may be judged from the experiments and observations to be found in this chapter.

It is confidently believed, that an elastic substance pervades the whole of space, and that the propagation of radiant energy from one locality in space to another takes place by a wave-like motion in this substance, just as the transmission of sound takes place by a wave-like motion in the atmosphere. In using the term *substance* in describing ether, it must not be forgotten, that ether is something altogether unlike matter as we recognise it in its various forms. **Matter we know**, by its properties, its inertia, and its susceptibility to the action of energy; but *the existence of ether we can only infer*, from the phenomena of radiation, and the effects of light, heat, and electricity. And inasmuch as the agent of these changes is a hypothetical medium, and the changes themselves are of a very subtle and complex character, it is evident that questions connected with ether must be left to the last stage of our course, and that the highest mental qualities are needed for their consideration. It is as well to state here, that the facts of wave-motion are not easy to understand when they are observed to take place in ordinary phenomenal matter, and they are obviously far more difficult to understand as taking place in a hypothetical medium, the existence of which is only known to us indirectly and by inference.

The phenomena of light are, unfortunately perhaps, capable of very superficial treatment. The ordinary *geometrical* treatment of reflection and refraction is very easy to follow, and the results are perfectly accurate. But it is based upon assumptions which must be understood, if any further investigations of the subject are to be possible. There are certain serious obstacles to a proper comprehension of the facts of light, and these are usually slurred over with distinct disadvantage to the student. In what follows we shall deal with the more obvious and superficial results of luminous vibrations in the first place, and then endeavour to consider them from the point of view of *waves of varying amplitude*, travelling symmetrically in all directions in a universally existing elastic substance.

But before we deal with a state of affairs which makes serious demands on the faculty of imagination, a few remarks may be made on the more directly demonstrable facts of wave-motion in

air. The rate at which sound travels in air is about 1100 ft. per second. This is a speed which is difficult enough for us to follow, and it is far from easy to grasp the mechanism by which such a rapid transmission takes place. But when we come to consider the propagation of light, we are told that skilful investigators attribute to it a possible speed of 186,000 miles a second. A mode of motion which can travel at this rate is truly hard to understand, and the ordinary experience of our senses gives us very little aid in trying to realise a mechanism, which carries an almost instantaneous tremor through such vast spaces, in exact correspondence with every minute oscillation set up in a particle of matter.

PRACTICAL WORK IN SOUND.

The Transverse Vibration of a Rod fixed at one End.—A stout piece of brass wire, about four or five feet long and made quite straight, is firmly fixed at one end in a clamp. If pulled aside and released, it vibrates through its whole length.

The wire may, however, be made to vibrate in other fashions. Hold it at about one-third of its length away from the free end, then start it vibrating between the fixed points, and meanwhile remove your hand. It may be made

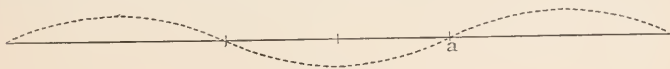


FIG. 51.

to vibrate as shown in Fig. 51, exhibiting a stationary point or node at a . If it is held at about one-fifth from its free end, Fig. 52, and likewise at the

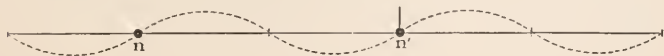


FIG. 52.

middle of the longer part, the rod will oscillate, and present two nodes or relatively fixed points.

Now in this and similar cases the frequency of the vibration (*frequency* is the reciprocal of *period*, since the number of vibrations in a given period of time depends upon the time taken by each one) is *inversely as the square of the free length vibrating*. Taking the frequency, when the whole length vibrates, as 1,

then in the second case the free length up to the first node is one-third of the whole length. In the third case it is one-fifth of the whole, and, in consequence, the frequencies in the three cases are as 1, 3^2 , and 5^2 , or 1, 9, and 25.

THE VIBRATION OF A STRETCHED STRING OR WIRE.

If a board, or better still, a hollow wooden box, over a yard long, be provided with a wire stretched over a wooden bridge at each end, many effects in the production of sound may be investigated. The instrument is called a **sonometer**. The wire is firmly fixed at one end, passes over the two wooden triangular bridges which may be shifted in position, then passes over a pulley, and is finally stretched by a weight hanging from it. The wooden bridges stop the vibrations, and the length of wire contained between these limits together with the tension and density of the wire are the chief factors in deciding the nature of the vibrations.

When such a stretched wire is plucked, more than one mode of transverse vibration may take place, but the most prominent one is that due to the to-and-fro movement of the whole length of the wire. This vibration gives a certain note, that is, the effect made upon our auditory centre by the stimulus conveyed through the air to the ear, and thence by the auditory nerve to the brain, depends upon the *length* of the wire and upon its *tension*. If different lengths are used, a difference is perceived by the ear. The effect varies in degree though not in kind. In other words, a different **musical note** is given.

The medium of communication between the wire and the ear is the air, and all our hearing takes place through the air, whether it be of musical tones or noises. The pleasantness, or musical character, of a sensation is caused by the regularity of the impulses which reach the ear. Confused and irregular movements of air give us the sensation of *ordinary sound or noise*. But it is important to note, that even regular impulses do not produce a pleasurable sensation, unless they reach the ear with a certain *minimum of frequency*. An evenly repeated knock gradually passes into a musical note, if it be quickened in speed. It begins in that case as a musical note which is very low in the scale, and becomes higher and shriller, altering in **pitch** as the frequency increases. The tone varies

with the *frequency of the impulse*, or, to put it in other words, with the diminution in the period of the vibration, passing from one end of the **musical scale** to the other.

But the prominent vibration, hitherto described as taking place when a stretched wire is plucked or struck, is not the only one. It is easy to see that subordinate vibrations also occur, and it is easy to detect the effect made upon the ear by these subordinate vibrations. They give rise to various notes related in a certain manner to the **fundamental note**, and they are mainly those called the *octave*, its *fifth*, *second octave* and its *major third*, in musical notation. The frequencies of the fundamental and its *partial tones* are in the ratio of the prime numbers, 1, 2, 3, 4, etc.

SUGGESTED OBSERVATIONS.

Ascertain the various notes given by various lengths of vibrating wire. The variation in length is obtained by adjusting the distances of the bridges from one another.

Ascertain the effect of varying the tension of the wire by adding weights to the end.

Place under the wire a small triangular iron slide in which a notch has been filed. This slide should be just large enough for the wire to rest in the notch without any alteration in its tension. The vibration of the wire is now restricted. A node is formed where the wire is touched, and the vibrations of the rest of the wire must be in accordance with this and corresponding nodes. The dominant note obtained for different positions of the slide should be tested.

Wires of different thicknesses should also be used, and the variations in tone observed.

Note.—When there is any doubt as to the positions at which nodes exist, and that is a common occurrence, it is advisable to use a light rider made of a very small piece of paper. By repeated trial the positions in which the paper is not flicked off the wire are ascertained, and these are nodes.

Compare the frequency with which a stretched wire vibrates with the frequency of a tuning-fork. The wire may be stretched tighter or shortened in length in order to agree in frequency with the tuning-fork. When they agree, they both emit the same note. A **tuning-fork** is merely a rod fixed at its centre and for convenience bent double. Note that when the wire is “in tune” with the fork, the latter, when vibrating near it, starts vibrations in the wire through the medium of the air alone. The vibrations may be seen or heard, or indicated by the little paper riders.

The frequency with which a body vibrates, provided it emits a definite musical note, may be ascertained by comparing its note with that of standardised tuning-forks.

VIBRATIONS OF COLUMNS OF AIR.

It is noteworthy that many stringed instruments are rendered more resonant by means of vibration of the air contained in the hollow cavities with which they are provided. The effect in the case of the violin, 'cello, and others is familiar. The air within the hollow space increases the *loudness* of the note without altering its pitch (or frequency). The increased loudness of a tuning-fork, when placed upon a hollow box of appropriate length, is remarkable. But a question arises as to what is the appropriate length, and what is the connection between a given note and the volume of air which starts vibrating in unison with it.

OBSERVATIONS.

The length of a column of air corresponding with a given note may be readily measured. A wide cylinder is used, and it is nearly filled with water. A narrower open tube is now raised or lowered inside the cylinder, the water in the cylinder falling or rising within the open tube, so as to permit an easy adjustment of the length of the column of air within the tube.

The same result may be obtained, though less neatly, with a cylinder alone, by adding water to the cylinder until the right length of column is found.

A tuning-fork is struck and held near the open end of the tube. By varying the position of the tube a column of air will be found eventually to resound vigorously to the fork. The column is of the right length to augment the vibrations of the fork.

The resonator of the tuning-fork itself may be compared as regards its internal dimensions with the column found. The chief dimension, though not the sole factor in the result, is the length of the column which vibrates.

Air conveys sound by a succession of states of *condensation* and *rarefaction*. The first effects of a blow due to any sudden movement, whether of a plucked string or the impact of solid bodies, is to start a condensation of air in the neighbourhood. The

particles of air are pushed together, and in the case of vibration, the condensation when the body moves forward is followed by a rarefaction as the body moves backward, and these events alternate with one another, spreading outwards from the origin of sound and affecting wider and wider regions.

States of condensation and rarefaction must succeed one another within the cylinder used in the previous experiment, and the distance between successive points of rarefaction or of condensation constitutes the **wave-length**, and determines the character of the note emitted or resounded to. This consideration decides whether or not the column of air is of the right length to resound to the tuning-fork. The length of the column of air must clearly have some *simple relation* to the length of the wave corresponding with the note which is sounded. It is perfectly obvious that the closed end of the tube or cylinder must form a limit to the progression of the wave. Whether it is a condensation or rarefaction which occurs at the bottom of the vessel, it can go no farther, and it must be turned back. If the vessel is just long enough, to allow the wave to travel down it and be reflected back in just the right phase to aid the movement of the prong of the fork, then we have an increase in the amplitude of the wave of sound, and this is called resonance. The two vibrating objects, fork and column, act together as the origin of the same note.

If the position of maximum resonance, or the length of an air column which most strongly reinforces the vibrations of the fork, be found out, we have a means of measuring the frequency corresponding with the given note. The impulse reflected from the bottom of the vessel has to reach the fork again, when it is moving in the opposite direction to that in which it was moving when the impulse was originally given to the air. This fact gives us the clue to the meaning of *frequency* and *wave-length*. Speed of sound in air has a fairly constant value, and the disturbance must travel twice the length of the tube while the fork makes one-half of its full oscillation, *i.e.* once to-and-fro. The same fact is expressed by saying, that the fundamental note emitted has a wave-length of *four times the length of the tube*. It is easy to see, that, if we are given the value for the speed of

sound in air, we can ascertain the vibration-frequency of the fork, or, if we know the frequency of the fork, we can calculate the speed of sound in air.

The speed of sound in air is a value dependent upon the elasticity of air. The transmission of sound in any kind of matter is dependent upon its elasticity and its density in a manner represented by the formula $V = \sqrt{\frac{e}{d}}$.

Note.—It may be mentioned, that, when we speak of the propagation of sound, we refer to the rate at which a *periodic pulse* is transmitted through the air. What travels through the air is a series of compressions and rarefactions. Sound is, in reality, the *interpretation* given to these facts by our mind. **Sound is the name of a sensation.** A description of some of the terms, commonly met with in connection with sound, is given below.

An **oscillation** is a complete to-and-fro motion. A simple vibration or oscillation is a term often used in referring to a single displacement in one direction only, the single swing of a pendulum, for example.

The **loudness** of a sound depends upon the amplitude of the oscillations. Two notes may be alike as regards their period or frequency. That is, they may be of the same pitch, while they may differ in intensity because of the greater amplitude or swing of the disturbed particles of air.

The **pitch** of a sound depends upon the frequency with which the oscillatory disturbance takes place. The more rapidly the impulses reach the ear, the higher is the pitch.

Quality in a note is probably due to variation in the *form* of vibration, owing to variation in the number and intensity of the constituent motions. The same note sounded on a piano, violin, or clarinet will possess a different quality, though the frequency of the fundamental vibrations may be alike in each.

PRACTICAL WORK ON LIGHT.

Light appears to travel in Straight Lines.—The apparent transmission of light along straight lines is a familiar

experience. We cannot see round a corner. A small opaque body placed before our eyes cuts off light from luminous bodies in a straight line behind it. The shadowing of space behind an opaque body illustrates the same fact, that the effects of light are produced along straight lines. The illumination of particles of dust by a ray of light, or of particles of cloud by a ray of sunlight, so as to present under favourable circumstances straight lines of light, helps to strengthen our belief in a species of rectilinear propagation for light. The term *radiation* itself carries with it the same meaning. Yet it is important to remember in using these terms, if there is anything absolutely essential to the ether theory of light, it is that the vibrations which cause light are transmitted **equally in all directions by spherical waves.**

If it be necessary to demonstrate what is well known, make small holes in three pieces of card-board, and observe that when they are fixed at some distance apart, a light placed behind them is visible through the three holes only when they are in a straight line. A slight movement of one of the screens causes an obstruction of the light.

Reflection of Light.—When light falls upon the surface of any body, it is in some degree turned back or reflected. If the surface be irregular, then the reflection is irregular, but the smoother the surface, the greater is the fraction of the light undergoing regular reflection. We are able to perceive objects by the light *reflected from their surface*, and we estimate the shape and dimensions of a body by the manner in which light is reflected from its surface.

Laws of Reflection.—Fix a piece of silvered glass upright in a strip of wood. Scratch away a small portion of the silvering at the centre. Place the mirror upon a sheet of paper, and stick in two pins in front of the mirror and one behind it, in such positions that the reflected image of one pin in front may appear in a straight line with the other pin in front and the pin behind, as seen through the small clear space in the mirror. Draw lines, with the aid of a straight-edge, to mark the direction of the incident and reflected rays (assuming that straight lines represent the manner in which light is transmitted), rule a line also to mark the position of the mirror. Make several observations with the pins in different positions, and observe, that in each case the line, drawn to represent the direction of the incident

ray, makes the *same angle* with the mirror as the line representing the direction of the reflected ray.

But the observation may now be extended. Arrange the pin which is behind the mirror very carefully, so that it agrees in size and appearance, and partly coincides in apparent position, with the image of a pin placed in front. Fix another pin in front to be in a straight line with them. Draw lines as before and note, that the pin placed behind the mirror and coinciding with the apparent position of the image is exactly the *same distance* behind the mirror, as the pin, giving rise to the image, is in front of the mirror. Moreover, it is *directly behind* the pin giving rise to the image, so that the line joining them cuts the mirror at right angles.

Now this fact in itself may be utilised as a proof of the equality of the angles of incidence and reflection. If the mirror be represented by the line AB (Fig. 53), the pin giving rise to the

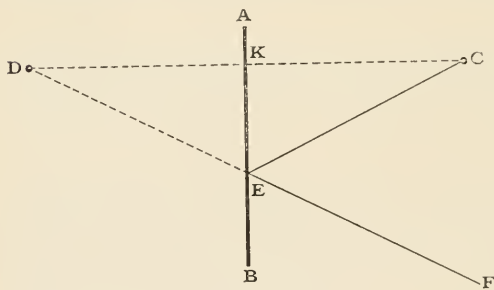


FIG. 53.

image by C , the apparent position of its image by D , and the direction of the ray of light by CEF , then by joining CD and DE , it is easy to see by geometry, that the angles CEK and FEB are equal if

DK is equal to CK . The two triangles EDK and ECK are similar, KE common to them, and DK equal to CK , together with the angles enclosed by these lines. Under these circumstances the triangles are equal in all respects, and therefore the angle DEK is equal to the angle CEK . But Euclid proves for us that the angle BEF is equal to DEK (Prop. xv. Bk. i.), and therefore to CEK . We are assuming, however, for this purpose, that FED is a straight line, but direct observation is the basis of this assumption. It is the straight line along which the image has been seen.

Note.—The accuracy of these observations is dependent upon the lines representing direction being truly drawn, and also upon

care being taken to fix the object which is behind the mirror, so as to coincide exactly in position and size with the image appearing there. In order to permit the partial coincidence of the image with the object behind the mirror, it is an advantage to scrape away a portion of the "silvering" of the mirror. A portion of the object may then be made to occupy the place of part of the image.

From the apparatus described we may also demonstrate another fact of reflection, namely, that the directions of the incident and reflected rays lie in the *same plane*, and that this plane is normal, *i.e.* at right angles to the reflecting surface.

Laws of Refraction. — These may be illustrated very simply. A rectangular piece of thick glass (such as is usually provided in boxes of weights to protect the small weights serves very well) is placed on a sheet of paper. Place two pins on one side of the glass and arrange two others on the other side, so that on looking through the glass and at all four pins, they appear in line. Some care will be needed in adjusting the pins.

Remove the glass and join the holes, made by the pins when placed in the proper position, by straight lines. The direction taken by the three straight lines is shown in Fig. 54. The deviation or **refraction** of the light due to the glass is represented by the angle abc . Note that the emerging ray is parallel to the entering ray when, as in this case, the sides of the glass are parallel.

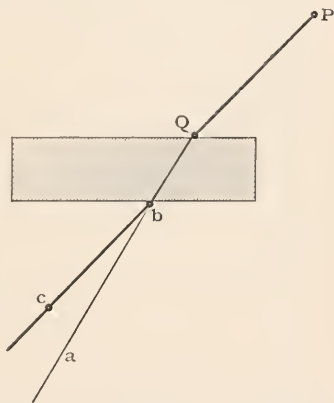


FIG. 54.—Arrangement of glass plate and pins for showing refraction.

When a ray of light enters a medium, such as glass, which is *optically denser* than the air, at an angle, it is turned aside or refracted. The extent to which it is turned aside depends upon the substance, but there is always *the same relation for the same media* between the incident and the refracted angle. However we may vary the angle, the incident ray bears to the refracted ray a relation as to direction which is expressed as the **refractive**

index. This ratio or refractive index is a number, expressing the relative magnitudes of the angles, made by the incident ray and the refracted ray, respectively, with the normal to the surface at which refraction takes place. The relation between the sine of the angle EBF and the sine of the angle CBD , is

$$\frac{\sin EBF}{\sin CBD} = \text{refractive index.}$$

The perpendiculars dropped on the normal, at equal distances from B along the incident and refracted rays, are in the same ratio as the sines of the respective angles.

Refraction through a Prism.—The path of a ray of light through a prism may be observed by the same plan as that adopted with a glass plate with parallel sides. In the prism, the surfaces at which the light enters

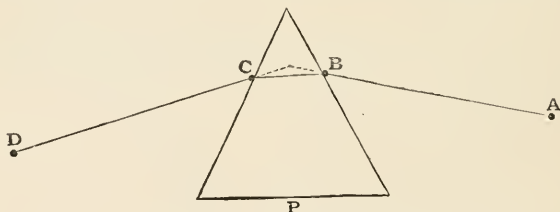


FIG. 55.—Diagram illustrating refraction through a prism.

and leaves the glass are inclined at an angle, usually an angle of about 60° . Four pins are so arranged, two on each side of the prism, that they appear in the same line. Lines drawn between the positions occupied by the pins, and showing the position of the prism itself, will display an appearance resembling the diagram shown in Fig. 55. The course of the ray is shown by the line $ABCD$. By continuing the lines AB and DC far enough, it is easy to ascertain the angle through which the ray has been refracted by passing through the prism.

Refraction of Light by a Lens.—There are various shaped lenses, but in all of them the optical effects are produced by the faces being curved. In the bending produced by a prism it is noticeable, that the light is turned towards the thicker part of the prism, towards the base in fact. Now if we place two prisms base to base, we get something approaching the shape of an ordinary convex lens, and the effect on light would be alike in both cases. It would converge, more or less,

to a point some little distance on the other side of the double prism or lens. If we were to place two prisms edge to edge, we should obtain a divergence of light, and this is what occurs with a concave lens, which resembles somewhat two prisms placed edge to edge.

The point to which light converges is called the **focus**. The point to which light *appears* to converge is also a focus. It is then called a *virtual* focus. The point at which parallel rays meet after passing through a lens in this way is called the **principal**

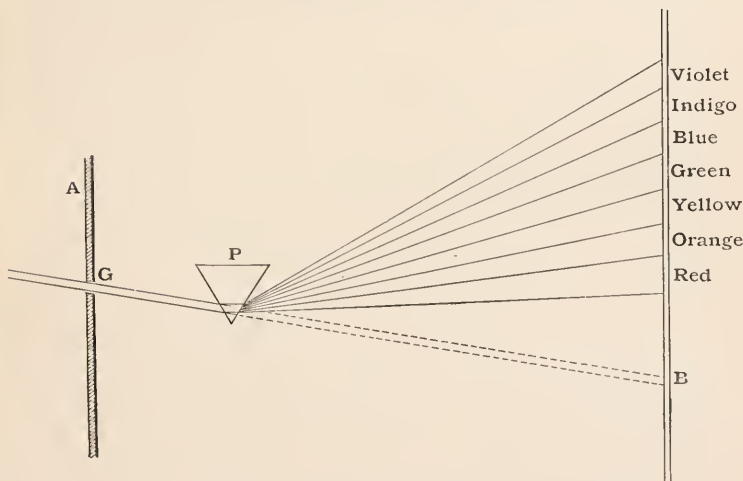


FIG. 56.—Decomposition of a beam of white light by a prism.

focus, and it varies in its distance from the lens in accordance with the shape of the lens. It is readily exhibited by causing a convex lens to throw an image of a window upon a screen placed behind it. The more curved the surface of the lens, the shorter is the **focal length**, or distance of this focus from the lens. The shorter the focal length of a lens, the higher is its magnifying power, as may be gathered by handling a few lenses.

Light decomposed by a Prism.—Allow bright light from an electric lamp or oil lamp, or still better from the sun, to pass through a small slit and impinge upon the face of a prism as shown in Fig. 56. If a screen be

now placed at a small distance away from the prism, an appearance known as the **spectrum** is obtained. Light is not only refracted by a prism, it is resolved into its component parts, and so we obtain from white light a succession of colours of which the prominent hues are violet, indigo, blue, green, yellow, orange, and red. The violet end of the spectrum is that which is most refracted from the original direction of the ray, and the red is the end which is least bent. White light appears then to be made up of all the various colours, and their appearance under the circumstances of this experiment is explained by a difference in **refrangibility**. In accordance with the wave-theory of light, white light is a mixture of a number of waves of different wave-lengths, and the shorter wave-lengths are more *impeded* than long ones in their passage through the prism, and in consequence more *refracted*.

If another prism be fixed, in a reversed position, in the path of the ray which has been decomposed into its constituent colours, the *reversal* of the phenomenon takes place, and the spectrum disappears. The effects which make up what is called dispersion at the first prism are annulled by the influence of the second, and if a screen be placed in position, we shall perceive a white spot. This may be regarded as proving, that the light is changed again into the state in which it entered the first prism.

An interesting demonstration of the nature of white light may be shown by rapidly rotating a round piece of card-board exhibiting sectors, painted as closely as possible in the various colours of the spectrum. The effect produced by this many-coloured wheel in motion is that of a dull grey surface. The more nearly we approach the actual colours of the spectrum, the whiter will be the appearance presented. But it is clear that a succession of sectors coloured with crude violet, indigo, blue, green, yellow, orange, and red, is a poor imitation of the infinitely varied hues of the spectrum. A little deeper research into the subject of colour will inform us of other reasons, why we can only approximate to whiteness under these circumstances.

A large grooved wheel turned by a handle, and connected by a cord with a small wheel on an axle carrying the disc, is needed in order to obtain rapid rotation, and it is important that the disc should be firmly fixed by the aid of a nut and large washers. By the use of various coloured discs provided with slits, cut from the circumference to the centre and made to overlap one another to various extents, interesting effects in the combination of colour

may be produced. These results may be compared with, though they will not necessarily resemble, the effects produced by mixing various pigments together.

It is not difficult to realise, that colour is an effect dependent upon the absorbent qualities possessed by a body. A flower is red, because it absorbs all the colours shown in the spectrum but the red. A leaf is green, because the green part of white light is alone reflected from its surface, the rest being absorbed. Variations in the quality of the colour exhibited by different objects are often due to the mingling of a certain amount of unchanged reflected light with some which has undergone partial absorption.

Hold some common salt on a platinum wire or foil in the flame of a bunsen burner, so that a bright yellow light is obtained, and note that a bright red object loses its colour when illuminated by it. It becomes ashen or colourless, since there are no red waves in the sodium light to be reflected. It shows red only when the light falling on it possesses red waves.

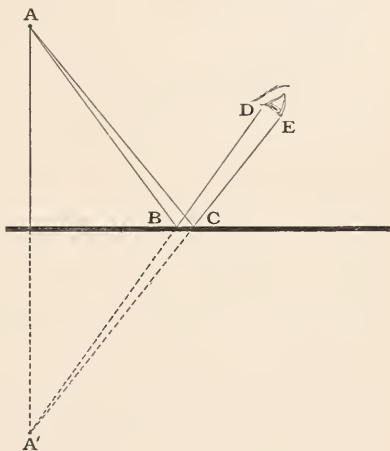


FIG. 57.—Formation of an image by a plane mirror.

ADDITIONAL EFFECTS OF REFLECTION AND REFRACTION.

Image in Plane Mirror.—The equal inclination shown by the incident and reflected rays may be taken into account, in considering the manner in which an image is formed by a plane mirror. A small object placed at *A* (Fig. 57) may be supposed to yield a ray of light *ABC*, which is reflected in the form of *BCDE*, and enters the eye placed at *DE*. But to the eye itself, which is incapable of judging anything about the previous history of the light, the ray appears to come from behind the mirror, from an object *A'* in the direction indicated by the dotted lines. From the geometrical construc-

tion of the figure it is easy to prove, that the image appears at the same distance behind the mirror as the object is in front of it.

Images produced by Two Plane Mirrors.—If two plane mirrors are

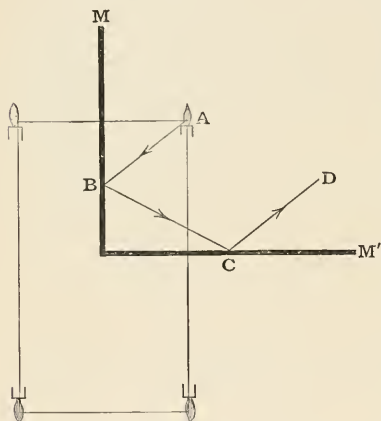


FIG. 58.—Formation of images by two mirrors placed at right angles to one another.

placed at right angles, an object placed within the angle will be found to give rise to three separate images in the position shown in the diagram (Fig. 58). It is evident that each mirror will present its own image as an effect of simple reflection, but in addition to these a third image appears, on account of the *double reflection* shown by the course of the line *ABCD*.

Reflection from a Spherical Mirror.—The centre of the sphere, of which a *spherical mirror* may be considered to form part, is called the centre of curvature. Lines drawn from this point to the mirror will be radii of the sphere, and will

be at right angles to the tangents drawn to these points. Light from a luminous object placed near the mirror will be reflected, so that the incident and reflected rays make equal angles with these radii (which is the same

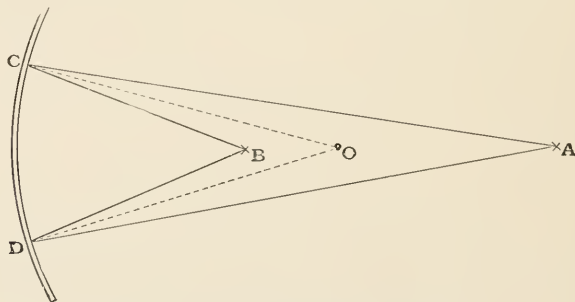


FIG. 59.—Reflection from a spherical mirror.

as making equal angles with the reflecting surface or with the tangents drawn to the reflecting point). In the diagram (Fig. 59), light from the object *A* is reflected so as to appear again at the point *B*, as indicated by

the lines ACB , ADB , making, for nearly normal incidence, equal angles with the radii OC and OD . The points A and B are **conjugate foci**.

If light from a distant object impinge on the mirror, it will be focused at a point half-way between the centre of curvature of the mirror and the mirror itself. This point is called the **principal focus** of the mirror. It is easy to prove geometrically, that this point is half-way between the centre of curvature and the mirror, provided the incident and reflected light always make equal angles with the radii of the spherical surface, that is, with the normal at the point of reflection. The principal focus may be practically demonstrated by turning the mirror to the sun and placing a piece of paper at the calculated distance. The paper will probably be charred, if the right position has been found.

The effects produced by a spherical mirror in reflecting light, as indicated by the images presented by objects placed at varying distances from it, should be investigated. The effects produced also by a convex spherical mirror, as distinct from the concave mirror, should be observed, and *diagrams should be drawn* to show the course taken by the light.

The distinction between **real** and **virtual images** is an important one and may be demonstrated practically by the use of these mirrors. A virtual image is one which appears to be behind the mirror at a place to which light cannot have penetrated. A real image is produced by an actual assemblage of light somewhere in front of the mirror.

Find by actual experiment the position at which a pin point, placed in front of a concave mirror, produces an inverted image of the pin, of which the point coincides in position with the real point and corresponds with it in size. The coincidence must be such, that on moving the eyes sideways the image and the pin do not separate.

Explain by means of a diagram, that this position is the geometrical centre of the mirror.

Effects due to Refraction.—The curiously bent appearance, presented by a stick which is placed in water, is an effect of **refraction**. It is an interesting exercise to note in the first place what actually appears, and then to draw a diagram showing that it is an effect of refraction.

Again, fill a glass cylinder with water, after placing an object at the bottom. Note that this object, when you look down upon it, appears nearer than it really is to the surface of the water.

The index of refraction for water, that is, the ratio $\frac{\sin a}{\sin b}$, when a is the angle of incidence from air, and b the angle of refraction in water, may be estimated roughly, by placing an object outside the cylinder at a depth which appears the same as that of the refracted image. The ratio of the true depth to the apparent depth is the same as the ratio $\frac{\tan a}{\tan b}$.

The Spectroscope.—The spectrum has been described as the effect produced when light passes through a prism, but the effect is not always clear or definite. It may be obtained in a condition which admits more readily of investigation by making use of certain precautions. If a convex lens is interposed between the prism and the slit, and the position of the lens is such, that the slit is at the principal focus, the light entering the prism will be parallel. The spectrum obtained on the other side of the prism will then be more distinct, and the colours be less likely to overlap. In addition to this precaution, it is important to place the prism in such a position, that the ray of light passes through it symmetrically, *i.e.* parallel to its base. It is found out by experiment, and it is deducible from theoretical considerations, that the light is more completely dispersed, and the spectrum more distinct, when this position is found. The position in question gives us what is called the **angle of minimum deviation**. The result of the precautions here described is to furnish what is called a **pure spectrum**, as distinct from a confused one.

The spectroscope is an instrument in which these operations are effectively carried out. The tube containing an adjustable slit, and the lenses, by which the ray is prevented from diffusing, is called the collimator. The other tube is the telescope, through which the spectrum is enlarged without being otherwise altered. The telescope is first removed, and its eye-piece adjusted so as to present a clear image of the cross-wires, which are inserted for exactness in comparing distances. The eye-piece and cross-wires are then focused together, so that a distant object yields a clearly defined image, which should not vary its position with regard to the cross-wires when the eye is moved from side to side. Remove the prism and replace the telescope, turning it and levelling it, if necessary, so as to view the slit directly and in the middle of the field. If necessary, focus the collimator, so that the image of the slit is well defined. Replace the prism in such a position that a good horizontal spectrum is obtained, levelling if necessary,

The axes of the telescope and collimator, together with the graduated circle to which they are attached, should now be in the same plane, if the adjustments have been carefully made.

Instead of an ordinary white flame for illuminating the slit, we may now make use of the incandescent vapour of various substances, by placing them on platinum foil in the bunsen flame. Instead of the *continuous spectrum* we shall observe bright *lines*, varying in colour, number, and relative position with the substances used. By throwing the rays of the sun upon the slit by a reflector, we obtain a continuous spectrum containing a number of *dark lines* (absorption lines) characteristic of many of the elements.

ADDITIONAL EXERCISES.

To find the Angle of a Prism by Reflection.—Allow light from a pin, placed in front of the edge of the prism, to be reflected from each face. Place two pins, one of them close up to the face and the other six or nine inches away, in a position to be in a line with the image given by the reflection from one face. Place two other pins in a corresponding position for the image reflected from the other face. Mark the position of the prism, remove it, and draw lines to mark the course of the light.

The angle between the two reflected rays (and this may be measured by a protractor) should be equal to twice the angle of the prism, if the incident angle is equal to the reflected angle. A diagram should be drawn to explain the course of the argument. ABC is the prism. HB , the incident ray, is reflected as BD and BG .

The only difficulty in following this proof lies in the fact, that we need to consider the incident ray HB to fall upon *the very edge of the prism and yet be reflected from both faces*. The light really falls upon the edge and also upon each face close to the edge. If BE and BF be continuations of the two faces, then CEB and ABD are together equal to the angle EBF , and this is an angle equal to that of the prism. Therefore the whole angle GBD is equal to twice the angle of the prism.

A more refined and accurate method of finding the angle of a prism may be carried out by using the spectroscope. The positions of the reflected rays are made to correspond with the cross-wires of the telescope, and the angles are read on the graduated circle forming part of the instrument.

Deviation of Reflected Ray by Rotation of Mirror.

—It is easy to demonstrate, and easy to prove geometrically, that when a mirror rotates through a given angle, a ray of reflected light is made to deviate through twice that angle.

Place a plane mirror upright upon a sheet of paper, and stick two pins in a line with the image from a third pin, one of the two former pins being close against the mirror. Mark the position of the mirror by drawing a

line on the paper. Now turn the mirror through a small angle about the pin placed against it, allowing the pin to serve as a pivot. Observe the direction of the reflected image and mark it by a pin. Mark the second position of the mirror by another line. Measure by means of a protractor the angles made by the lines joining the pin marks, and also the angle through which the mirror has been turned. The angle through which the mirror has been turned will be found one-half the angle made by the two lines, representing the directions of the reflected ray for the two positions of the mirror.

The geometrical proof, based upon the fact that the incident and reflected rays make equal angles with the reflecting surface, is

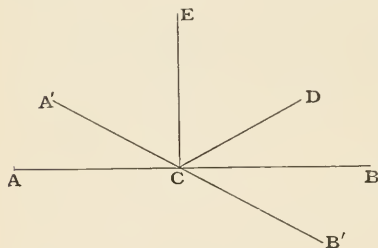


FIG. 60.

as follows. Fig. 60 shows the two positions of the mirror AB and $A'B'$. DC is the direction of the incident ray on each occasion. CA' is the reflected ray from AB , and CE is the direction of the reflected ray from the mirror when in the position $A'B'$. For

the convenience of demonstration, the mirror is made to take the same position as that previously occupied by the ray. Now by the law of reflection the angle $A'CA$ is equal to the angle DCB , and also the angle ECA' to the angle DCB' . But ACA' is also equal to BCB' (i. 15), therefore the whole angle DCB' is double the angle BCB' , and therefore, too, ECA' is double $A'CA$. That is, the deviation of the reflected ray is double the deviation of the mirror.

The manner in which the rotation of the mirror is related to the angle, through which the reflected ray is turned, is also apparent from the construction shown in Fig. 61. In this figure it will be seen—

$$\begin{aligned}
 a &= f && \text{(i. 15),} \\
 \text{and } b + c &= e + f && \text{(law of reflection);} \\
 \therefore a + b + c &= e + 2f && \text{(by addition of equals),} \\
 \text{since } e &= a + b && \text{(law of reflection),} \\
 c &= 2f;
 \end{aligned}$$

i.e. the reflected ray has been turned through twice the angle of rotation of the mirror.

Test of Plane Surface by Reflection.—Focus a telescope upon a given body, so that a clear and definite image is presented to the eye. Then incline the surface, so that an image of the body may be obtained through the telescope, after reflection at the surface. If the surface be plane, the image remains clear and well defined after reflection from the surface. If the surface to be tested be not movable, select for the telescope a position in which some object can be viewed both directly and after reflection.

Colour not a Permanent Quality.—Arrange a spectrum to appear upon a screen in a darkened room, using a prism, a lens, and a slit. Place various coloured bodies in different parts of the spectrum, and note the effect.

Interference of Sound-Waves.—Strike a tuning-fork, and turn it round on its axis, while it is vibrating near the ear. Notice that the sound waxes and wanes, while the fork is rotated. An effect is evidently taking place, which is comparable with the light and dark patches, produced by the interference and combination of light-waves, to be shortly described. In a certain position the vibrations from one prong of the fork interfere with those from another. What is the position?

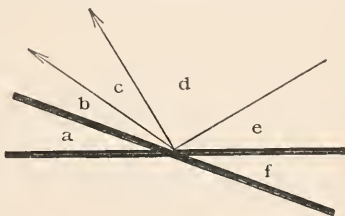


FIG. 61.

More Exact Description of Optical Phenomena.—The manner in which various effects of light have been

hitherto described may serve for most purposes, but it does not provide us with a satisfactory account of the *mechanism* by which these effects are produced. Something more is needed, before we can regard our knowledge of the subject as adequate or even accurate. It is not enough to draw straight lines to represent rays of light, though the straight lines, it may be readily admitted, are of great assistance in representing the effects which are observable. They can scarcely be regarded as a faithful representation of a vibratory motion, which, starting from the source of light, is propagated by spherical waves in all directions simultaneously. In the account which follows, details will be given more in accordance with the **wave-theory of light**, though the final results will not be found inconsistent with what has been already stated.

The Interference of Light.—It was first noticed by Young, that two rays of light, converging in a dark room from

two small holes close together, yield certain alternate light and dark bands, when a screen is placed where they overlap. The dark bands disappear when one ray is cut off. In other words, the addition of light may, under certain circumstances, produce *darkness*. We have already learnt from the use of a prism, that white light is the joint effect of light of various kinds or colours; and this is again shown by the observation, that the dark bands are alternated with coloured ones in this experiment, when white light is used, while with light of one colour, such as the yellow light given by sodium compounds, alternate bands of *black* and *yellow* alone are given.

Fresnel obtained a similar result more conveniently in two

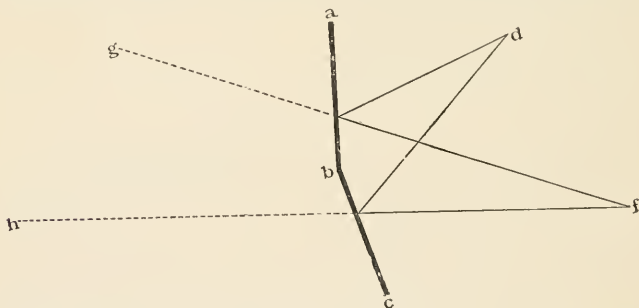


FIG. 62.—Apparatus for demonstrating interference produced by reflection.

ways: one by the aid of reflection, the other by means of refraction. In the first method, two metallic mirrors *ab* and *bc* (Fig. 62) are placed side by side, so as to be nearly in the same plane, but not quite. A ray of light from *d* is caused to fall upon both mirrors. The reflected rays converge to a point *f*, and apparently come from two vertical images, *g* and *h*, close together at the back of the mirrors. On placing a screen at *f*, alternate dark and light bands should be obtained.

In Fresnel's second experiment, a prism *abc* (Fig. 63) of very large angle, nearly 180° , called a **bi-prism**, is placed so that light diverging from the point *d* falls on the face *ac*. Part of the light is refracted by the portion *ab*, and part by the portion *cb*,

of the bi-prism. A given ray de is refracted and reaches a point p , as if it had come from g , while another ray df is refracted by the other portion of the bi-prism, and reaches the point p as if it had come from a point h . Hence the effect of these two rays at the point p is the same as if they had come respectively from the two points g and h , which are close together. A screen placed at p will exhibit the effects of **interference**.

A carefully constructed **optical bench** allows this effect to be observed, and the distance between the lines to be accurately measured. It consists of a heavy iron bed, planed, grooved and graduated, so that three upright stands may be moved along it, to distances measurable by the verniers they carry. The first stand

carries the eye-piece with a vertical cross-wire. This may be moved horizontally by a micrometer screw. A scale and vernier shows the displacement. The middle upright holds the bi-prism, and the

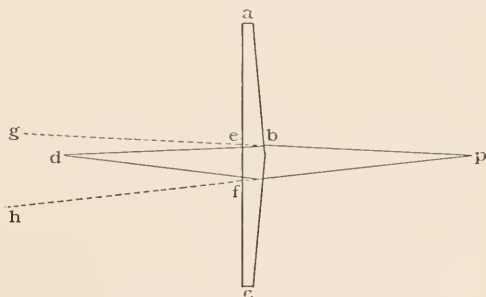


FIG. 63.—Bi-prism for showing interference.

farther one carries the slit. These two are capable of horizontal and vertical movements. The centres of the slit, bi-prism and eye-piece should be in a straight line parallel to the bench-scale. The edge of the bi-prism should be vertical and pass through this straight line. The cross-wire and slit should coincide with the edge of the bi-prism, and the cross-wire must move accurately at right angles to this line, in order to measure the distance apart of the interference lines.

Explanation of Interference.—The most complete explanation of the observed properties of light is given by a theory, according to which light consists of a vibratory motion of a universal medium, the ether. The ether allows this vibratory motion, when once it is set up, to be propagated with very great

rapidity and with undiminished intensity in all directions. Ether is present in matter as well as in space, occupying the spaces between the particles. Light may therefore pass through some kinds of matter; others are only slightly penetrated, the motion of the ether being probably obstructed or changed by the particles of matter. We are unable to observe ether directly. We are not conscious of its existence as we are of matter. Yet, by assuming the existence of such a medium, we are able to put forward a simple explanation of the most varied optical phenomena.

We are not concerned, at this stage, with the exact nature of the vibratory movement constituting light. We have simply to consider, that this vibratory movement is rapidly propagated without any portion of the ether undergoing more than a small excursion from its position of rest, just as a wave of water travels far and wide, while a body floating on the surface of the water shows by its motion up and down, that the *wave* travels, but not the water. The movement travels on, leaving the ether behind it unchanged. If it reaches our eyes with sufficient intensity, we are conscious of *light*. If it reaches the skin with any intensity, we have the sensation of *warmth*. When it falls upon a body, it may make it luminous or raise its temperature.

Whatever may be the state of the ether which is conveying radiation, we may be quite certain of one thing—that there are two *phases* of that state. At one time the movement is positive, at another negative. At one instant the displacement is in one direction, and the next it is equal in amount but opposite in direction. The distance between two points which are successively moving in the same manner is called the **length** of a wave or undulation. In other words, the length of a wave is the space through which the vibratory movement passes, during the time occupied in the complete vibration of any single portion of the ether. The total displacement of each portion of the ether from its original position is called the **amplitude** of the wave. Upon this depends the *intensity* of the light (and likewise of the thermal effects produced).

The joint effect of two ether-waves may be either an increased or diminished displacement—that is, the amplitude of the joint

wave at the point of coincidence may be larger or smaller than that of either of its constituent waves. The movement communicated by one travelling wave may be, at that given point, in the same direction as that communicated by the other wave. In this case the total displacement is equal to the sum of the separate displacements, and the intensity of light is greater than that from either source alone. If the displacements happen to be, however, in opposite directions, on account of the position of the point with regard to the concurring waves, then the resultant displacement will be the sum of a positive and a negative quantity, *i.e.* the difference between these quantities, and the direction will be that of the larger quantity. Hence there will be a *diminution of light*. If the two displacements are exactly equal and in opposite directions at the given point, then there is evidently no resultant motion at this point, and hence *no light*.

It is obvious that displacements which neutralise one another must be in the same plane, and in the case of light this plane must, from various observations, be perpendicular to the direction of propagation. Confirmation of this may be obtained from the behaviour of *polarised light*.

In order to measure the wave-length, λ , of a given kind of light, it is necessary to know the distance, x , between two consecutive bright bands, the distance, a , between the slit and the eye-piece, and the distance, c , between the two virtual images formed by the two halves of the prism. Then—

$$\lambda = \frac{cx}{a}.$$

By varying the light, or interposing coloured glasses between the slit and the bi-prism, the *variation in wave-length* may be measured by the same formula, the quantity x being the only variable. We shall find that the colours, in the order in which they are presented in the spectrum, vary in wave-length, the smallest wave-lengths being at the *violet* end, and the longest at the *red* end, the intermediate colours having intermediate wave-lengths.

Explanation of Rectilinear Propagation.—Although

the wave-theory of light has simply and reasonably explained several phenomena, we have to find some explanation for the *observed rectilinear propagation of light*, and for the *observed laws of reflection and refraction*.

It is contrary to observation that light should travel in one direction only. A source of light is visible from all directions, except so far as opaque matter prevents its passage. It would also be inconsistent with our assumption of the existence of a homogeneous ether to suppose, that a disturbance, set up by a radiating body, does not travel in the same manner, and with the same speed, in all directions in the same isotropic¹ medium. Since the sphere is the only body which is symmetrical in all directions with regard to space, a series of *spherical waves* are started in the ether, and extend farther and farther until obstructed or modified.

When the surface of another medium is reached, we have in general two new waves set up, each different in direction from the original. One is the *reflected* wave, the other the *refracted* wave. The relation in the amplitude of the vibrations, which will determine the *relative intensity* of the two waves of light, will vary for different media.

In the same medium, the *speed* at which light travels is unchanged. In a new medium, the speed may naturally alter. It has been clearly proved by direct observations, that the speed of propagation *does vary in different media*; but, whatever the speed, light always travels rectilinearly. We may, however, first apply the principle of interference to reconcile the wave-theory with the familiar fact, that an opaque body effectively shields a portion of the ether from disturbances which must be occurring in its neighbourhood.

Let WV (Fig. 64) represent a section of portion of a wave, starting from the luminous point O , and let P be the point at which the effect of this wave is considered. Join OP cutting WV , then let a, b, c, d, e, f , etc., represent points such that the linear distances aP, bP, cP, dP , etc., on one side the line, and likewise those, eP, fP, gP , etc., on the other side, differ each

¹ Similarly constituted in all directions, or without "grain."

from its neighbour by the distance of *half a wave-length*. Then, if we consider each of these points as the centre of a new disturbance, it is obvious that each consecutive pair of the secondary waves produced will arrive at *P* in *opposite phases*, and, if equal, would neutralise each other. That is, the general result of the portion *ab* will be opposite to that of the portion *bc*, and *cd* opposite in its effect to the next, and so on for the other portions of the wave.

But now, as the distance from the axis *OP* increases, the intensity of the disturbances rapidly lessens. The obliquity towards *P* is greater and the vibrations less effective. At a distance which is

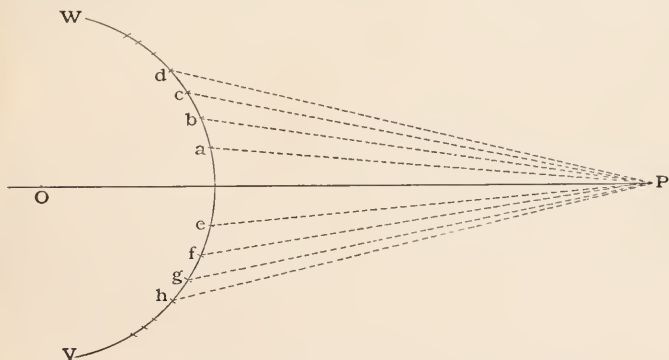


FIG. 64.—Diagram explaining rectilinear propagation of light.

very small, on account of the minuteness of the dimensions of light-waves, the effect of the subordinate disturbances from the original wave at the point *P* is negligible. Hence the effective portion of the wave consists of nothing but a small area which is on the straight line joining the luminous point with the spectator at *P*. For this reason, an obstacle placed on this line shuts off the light from *P*.

It will be evident from this explanation, that if alternate portions, *ab*, *cd*, etc., be stopped by opaque bodies, the total quantity of light reaching *P* will be increased. This will now be demonstrated by means of a **diffraction grating**.

The Diffraction Grating.—In observations with this

grating, we shall deal with light-waves of one kind—that is, of the same length—for the sake of simplicity. The apparatus consists of a number of very fine and very close parallel lines, which have been accurately ruled at equal distances, by means of a machine, on a piece of glass or metal. A photographic reproduction of such a grating answers every purpose.

The latter is placed in a vertical position on the small central table of the spectroscope, so that the yellow sodium light from the slit of the collimator falls upon it normally. On looking through the grating towards the slit, the direct image of the slit will be seen, and, in addition, several images on each side of the direct image growing fainter and fainter as they increase in distance. On bringing the cross-wires of the telescope to bear upon these images, and carefully adjusting, if needful, the level of any portion of the instrument, their angular distance from the central image, and from each other, may be very accurately read.

Let ab , a_1b_1 , a_2b_2 (Fig. 65) represent *in section* the opaque portions of the grating, P the position of the eye, and O the slit; then we may consider the grating to coincide with a very large light-wave, alternate portions of which are cut off by the opacity of the lines, while alternate portions are transmitted—a condition described in the last section. Without the grating we should see the slit directly; by means of the grating the interfering portions are intercepted, and so more than a direct view of the slit is obtained, and we see, in a fashion, around a corner.

Suppose that the distances of P from a_2 and from a_3 differ by a whole wave-length, then the light which would come from the portion a_2a_3 of the large wave may be considered to consist of two portions, which are nearly equal but in opposite phases; the line a_2b_2 , however, intercepts one portion completely or incompletely, according to the relative size of the opaque and transparent portions. A bright band will consequently be seen at Pa_3 , and this will be the first band. At another position a_6a_7 on the grating, the line Pa_6 will differ from Pa_7 by two whole wave-lengths; then the light which would come from the portion a_6a_7 may be considered to consist of two portions which will be in opposite phases. One of these being intercepted, a band is visible in the direction Pa_7 . This principle operates at all those positions

of the grating, where the corresponding distances differ by any whole number of wave-lengths. The position of these images

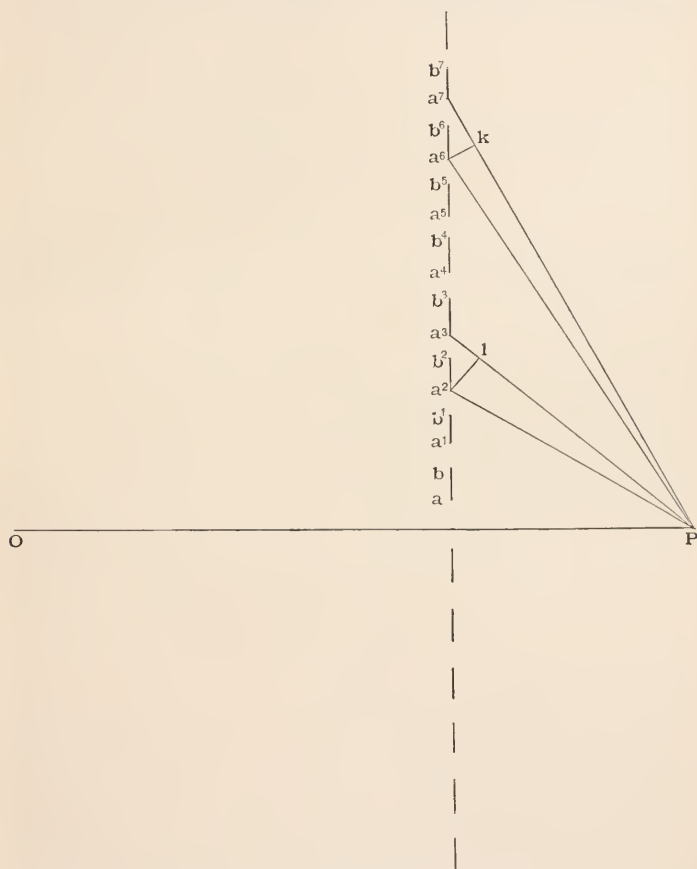


FIG. 65.—Diagram illustrating action of a diffraction grating.

will be determined solely by the length of the light-waves, and will vary for different colours.

If d denote the distance a_2a_3 , etc., that is, the interval composed of an opaque and a transparent portion of the grating (a

distance which is usually known for each grating), and λ denote the wave-length of the light used, then, by construction, we have for the position of the first image,

$$\frac{\lambda}{d} = \sin \theta, \text{ or } \lambda = d \sin \theta,$$

when θ is the angle a_3a_2I , or, which is the same, the angle OPa_3 . For the second image and the second angle θ_2 ,

$$\lambda = \frac{d}{2} \sin \theta_2, \text{ and so on.}$$

It is advisable in this observation to take the mean angle, obtained by measuring the corresponding images on each side of the main image. Precisely the same results, explicable in the same manner, may be obtained by reflection from lines ruled upon polished metal. When white light is used, several coloured bands may be obtained with either reflection or refraction gratings, since we shall now have each monochromatic image of the slit replaced by a spectrum, representing the succession of images, caused by *the various wave-lengths*. By constructing a diagram which shall include radiations of different wave-lengths, the progressive difference in the position of the images will be made clear.

Explanation of Reflection and Refraction.—The same principle of interference of light may now be applied to explain the observed laws of reflection and refraction in isotropic media—that is, media which do not interfere by their structure with the spherical propagation of ether-waves.

Each portion of the bounding surface of two such media with light incident upon it becomes a centre of disturbance, from which minor waves are propagated in each medium. The effect at a given point P (Fig. 66) in the one medium is the resultant of all the disturbances which reach it; and the effect at a given point p is the resultant of all the disturbances which reach that point through the other medium.

Suppose the incident wave-front be considered, for simplicity, as a straight line ab cutting the surface in a . Draw bc perpendicular to ab . (For the clear understanding of this argument, it is of the greatest importance that the whole diagram should be

accurately copied, step by step, on a larger scale, by the aid of compasses and rulers.) Then from a as centre, and with bc as radius, describe the partial circle dq . By the time the portion of the wave-front at b has reached the surface at C , the disturbance originated at a will have spread to all parts of the curve dx . Take intermediate points e and f on the wave-front ab , and draw perpendiculars from them to the surface. From the points g and h describe partial circles with radii equal to the respective distances which the wave-front at b has yet to travel in order to reach the surface, after the portions at e and f have respectively reached it. These distances will be je and hc , obtained by

P

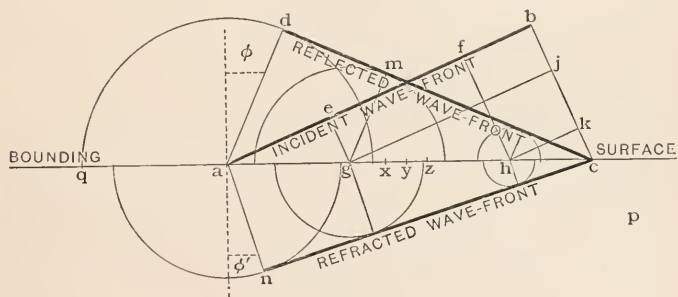


FIG. 66.

drawing parallels to the wave-front from the points g and h . A tangent drawn to these curves will now represent the **reflected wave-front**.

Let us now take several points on the surface ac , such that the displacements caused at the point m by the waves from consecutive portions, x, y, z , are in opposite directions—*i.e.* the distance of these points from m must vary by half wave-lengths. Then, as before demonstrated, the only *effective portion of the surface in illuminating the point m is the small area at g* , the displacement at which has been caused by the portion of the wave-front at e , the areas farther away more and more completely destroying one another's effects. The same reasoning applies to *every other portion* of the reflected wave-front, and hence the light

must be reflected in the direction gm, as represented by the wave-front *dc*, all disturbances in other directions being neutralised.

It is obvious from the construction that the reflected wave-front is inclined *at the same angle* to the reflecting surface as the incident wave-front, and that they are both in the same plane.

To the *refracted portion* of the wave, the same arguments and the same construction may be applied, with the exception of the modification required by the *difference in the speed* of the waves in the two media. The partial circle, which is drawn from the point *a* in the new medium, must have a radius *an* which shall bear to the distance *bc* the same ratio as the speed of light in the new medium bears to the speed in the old medium. The same ratio must be observed in the other cases, and a tangent drawn to the several partial circles in the new medium is seen to be deflected on account of this change of speed. It may be proved, by applying the principle of interference, as before, to represent the refracted wave-front.

The incident and refracted waves are in the same plane, and if ϕ and ϕ' stand respectively for the angles each makes with the normal to the surface, then, by geometry,

$$\frac{\sin \phi}{\sin \phi'} = \frac{bc}{an} \text{ or } \frac{v}{v'}.$$

Or, the sines of these angles are in the same ratio as the *speeds of light* in the two media, a ratio which is constant for the same media. Hence we may ascertain relative speeds by measuring refractive indices.

The most convenient method of measuring the refractive index of a body, if a solid, is to grind it to the form of a *prism*, measure the *angle of the prism* by reflection of light with the spectroscope, then measure the *angle of minimum deviation* when light passes through the substance. If a liquid, it is enclosed in a hollow prism, of which the sides are perfectly plane parallel-sided pieces of glass, and not able themselves to cause any total deviation. Measurements are then made as with a solid.

A table of refractive indices—that is, of the ratio $\frac{\sin \phi}{\sin \phi'}$ —for yellow sodium light from air is given below.

Table of Refractive Indices for the mean D line of Sodium.

Diamond	2.42	Crown glass	1.5
Ruby	1.71	Fluor spar	1.43
Iceland spar (ord.)	1.658	Ice	1.31
„ „ (ext.)	1.486	Carbon disulphide	1.63
Topaz	1.61	Benzene	1.49
Flint glass	1.6	Glycerin	1.47
Emerald	1.58	Turpentine	1.46
Quartz (ord.)	1.544	Alcohol (ethyl)	1.36
„ (ext.)	1.553	Ether (ethyl)	1.35
Rock salt	1.54	Water	1.33
Canada balsam	1.53	Alcohol (methyl)	1.33

Explanation of Spectra, with Observations.—In all the previous observations we have paid more attention to the *luminous* effects of radiation than to the *thermal* effects, but simple experiments suffice to show, that the observed changes possess their thermal aspect. For example, the focus of light is near the focus of temperature; the direction in which light is reflected or refracted is the direction along which the maximum heating effects are produced by the radiating centre. At the same time we must remember that ether-waves are likely to be checked or absorbed in varying degrees during their passage through various kinds of matter. If this be so, in accordance with the size and condition of the material particles which meet them, there will be some waves more completely absorbed than others. The mutual action of ether-waves with matter forms a wide field of investigation, which our past work should enable us to approach.

White light transmitted through blue glass appears blue, because the particles of the glass have *absorbed the rest* of the white light and *let through* only the blue. So it is for other colours. A coloured flower absorbs a portion of the sunlight incident upon it, reflecting only those waves which confer its particular colour. That a difference of wave-length constitutes

variety of colour may be readily demonstrated by interposing coloured transparent bodies, or changing the colour of the light, in interference experiments. The distance apart of the interference bands varies with different colours, and gives an opportunity of comparing the wave-lengths corresponding with the colours.

The **dispersion** of white light in passing through a prism is brought about by the fact, that the speed of *short waves* is more checked than that of larger waves in passing through the denser medium, and shorter waves are consequently *the more refracted*. A reference to the diagram explaining refraction will make this clear.

The dimensions of wave-lengths, found by experiments, are of the same magnitude as we should expect to find for waves, which are originated and influenced by particles of a size consistent with the molecular theory. Ether-waves, molecules, and atoms are physical phenomena of the same order, incapable of being directly observed, but yet apparent to reason. The nature of the movements among particles of matter, which give rise to these ether-waves, remains a matter for future investigation. So far, we can only say that it is a kind of vibration.

When the temperature of a body rises, the vibration increases in *amplitude*, and may change in character. A solid or liquid at a very high temperature emits **white light**. The constant collision of particles is probably that which brings about all kinds of vibrations, and hence ether-waves of all lengths. Many of these are, no doubt, invisible.

The particles of a gas, unless at a high pressure, suffer comparatively few collisions, and hence give out a few characteristic vibrations, forming distinct **line spectra**. Our main source of light, *the sun*, emits waves of all lengths, not only waves of light and heat, but those which do not affect our senses and have to be made apparent by special means. This is what we should expect from such a body as the sun.

The special line spectra, from which so much may be learnt as to the composition of bodies, must be studied cautiously. We shall find that the spectrum, characteristic of a given body at a

given temperature, is not necessarily the same as its spectrum at another temperature, or as the one yielded by an electric discharge passing through it. Also, a change of pressure may bring about modifications. Although conclusions must not be drawn too freely from spectroscopic observations, since a given vibration may be due to several others combining, or may be modified by neighbouring particles, yet they have become a most important means of analysis, far exceeding in delicacy any other method. New conceptions as to what is truly elementary matter have also been gained from spectroscopic investigations.

Another branch of spectroscopic work is the investigation of the results of *transmitting* ordinary light through incandescent vapours. We find under certain conditions, that the usual characteristic bright lines are replaced by **dark spaces**. In other words, the characteristic vibrations previously emitted are now absorbed. The particles of the vapour select and check those vibrations, which are, as it were, attuned to their own periods. It is obvious, if this result is to be obtained, that the vapour must not be at a temperature high enough to yield of itself a bright spectrum. These **absorption lines** are conveniently seen in the spectrum of the sun, which shows numerous dark spaces corresponding with the bright lines emitted by known terrestrial vapours. A less heated envelope of vapours, of very complex composition, surrounding the sun sifts out various portions of a spectrum in other respects quite continuous. A good reflection grating exhibits these lines very satisfactorily with the aid of a heliostat.

The main result of our observations of the movements of ether should be, to impress upon us the need of considering it as a possible agent in other changes. We have seen that it is capable of handing on the state of one portion of matter in one place to another portion in another place; we have seen that this is performed in a peculiarly subtle manner, and we can never consider that any of our knowledge of natural changes approaches completeness, until we understand, not only the changes of so-called *matter*, but also the changes of the *ether* in its neighbourhood. In the future, ether movements corresponding with magnetic and

electric disturbance will have to be investigated by the student, as well as further details about the theory of light, which may be gathered from what is called the **polarisation** of light. These and other conquests in the domain of nature are the result of persevering efforts in experiment, combined with accuracy of observation. And accuracy in matters of observation depends upon completeness. At the same time we have to remember, that the deeper observation goes, the more there is to observe.

The practical demonstration by Hertz of the transmission of electric disturbances by ether-waves, of the same character as light though of much greater length, has been a remarkable confirmation of suggestions to this effect, which were first made by Faraday and then worked out mathematically by Clerk Maxwell. This recently acquired insight into the mechanics of ether is probably destined to undergo remarkable developments in the future, and it is the future which will always possess the most potent attractions for the student of Science.

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